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MINI-RPV RECOVERY SYSTEM CONCEPTUAL STUDY

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Final Report

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distribution unlimited.

Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This report is considered to be an encompassing review of any and all recovery systems and concepts which could be used by the Army for recovery of 120- to 200-pound RPV's. The scope of this effort was to document and perform an assessment of these various systems. A detailed and in-depth analysis has not been accomplished, and variances in ranking may result.

The reader is advised that this effort and its results are intended to provide a basis for further analysis and should not be considered as a final assessment. More specifics are necessary to perform an appropriate and meaningful analysis for specific missions and flight profiles.

Thomas B. Allardice of the Military Operations Technology Division served as project engineer for this effort.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

This study investigates and evaluates Mini-RPV recovery concepts potentially suitable for the U.S. Army tactical environment. The air vehicle on which the recovery study is based is the U.S. Army/Lockheed Aquila, XMQM-105 Mini-RPV at a nominal gross weight of 120 pounds. A hypothetical RPV counterpart at 200 pounds gross weight is also used to bound the upper weight limit for Mini-RPVs.

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20. Abstract (continued)

The study is divided into three phases. Phase I, Initial Search & Selection includes: (1) a data survey conducted for the purpose of obtaining as much information as possible on concepts, designs and data pertinent to Mini-RPV recovery; (2) categorization of recovery concepts; (3) descriptions of recovery concepts, cursory analysis and concluding remarks; and (4) a largely subjective evaluation of the concepts to establish concept credibility and selection of ten concepts for further study.

Phase II, Final Concept Selection, treats the ten concepts surviving Phase I in terms of physical concepts for field deployment. Some additional analysis is performed as required. A quantitative evaluation is conducted in which parameters are established, values are weighed, ranked, and scored, and three concepts are selected for further study.

Phase III, Preferred System Selection, provides additional technical data and hardware development and cost information on three recovery concepts carried over from Phase II. The three concepts are: (1) parachute, surface impact; (2) a traveling net with a retraction feature; and (3) a traveling net plus an air-inflatable impact platform. Another quantitative evaluation is conducted which indicates that the ranking of the three concepts is close, with the parachute system slightly more advantageous than the other two concepts.

As a result of the Mini-RPV recovery concept investigations and evaluations conducted in this study, it is recommended that in-depth studies be initiated to provide information for higher level evaluations based on detailed technical definitions including systems implications and tactical employment problems related to both the parachute and the traveling net recovery systems.

PREFACE

This report was prepared by Teledyne Ryan Aeronautical, under the authority of the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, Contract DAAJ02-76-C-0048, and under the technical supervision of Thomas B. Allardice.

The author acknowledges the technical assistance furnished by Messrs. P.F. Girard, H.A. James, T.C. Nietz, A.J. Navoy, G. C. Noonan, Jr., J.M. Silas; the help of many other members of the Teledyne Ryan staff; and the response to Teledyne Ryan inquiries by private citizens, industry, Universities and Government agencies.

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1.0 INTRODUCTION

The Mini-RPV is emerging as a military air vehicle candidate with potential use by U.S. Army battlefield units for the collection and utilization of tactical information. It follows that the associated support elements for the RPV system would be developed concurrent with the air vehicle.

An important support element, the subject of this study, is a field deployable recovery system which can be integrated into the existing U.S. Army logistical structure and can be operated in a tactical environment. As stated in the request for quotation (DAA-J02-76-C-0096) that preceded this study, the recovery phase of the RPV mission is subject to many constraints, but in general the equipment employed must be simple, lightweight, and reliable. It must also interface with the ground forces by being usable at alternate locations and should not provide unusual or unique radar, optical, acoustical, or electronic signatures which could be identified with the specific operational mission.

The overall objective of this study is to identify, investigate and evaluate Mini-RPV recovery concept candidates with a view to selecting a preferred candidate judged to meet the general requirements stated above.

The study is structured in three phases. Phase I, Initial Search and Selection, begins with a data survey to identify all possible recovery concept candidates. The data survey included: (1) the standard Defense Documentation Center literature search and Teledyne Ryan Aeronautical in-house sources to establish a bibliography; (2) letters of solicitation mailed to U.S. and foreign industry, U.S. Government agencies and universities; (3) a patent search; and (4) a magazine advertisement seeking concepts and ideas. The concepts identified are listed in Section 6, Table 1.

The recovery concepts are then categorized in two groups: I Surface-Impact, and II Above-Surface-Recovery. They are then described, a cursory analysis is performed where feasible, and the concept is then reviewed in concluding remarks. An evaluation of the concept is then conducted which resulted in ten concepts which are considered to be credible to be carried forward for further study. The evaluation is based partly on quantitative data and some subjective engineering judgement. The concepts set aside are listed along with the reasons for rejection in Section 8, Table 7.

In Phase II, Final Concept Selection, the studies generally emphasize the physical aspects of field deployment of the ten credible candidate recovery concepts carried over from Phase I. However, in some instances, additional analysis is conducted where it was determined that some effort was needed to implement the intent of Phase II.

The Phase II evaluation procedure begins with the development of a detailed list of 65 parameters describing the recovery concepts. Values for the parameters are based on a quantitative number, if available, or the item is weighted on a scale of one through ten, with ten being best. The results of the Phase II evaluations indicate that the Parachute I-2A (Surface-Impact) concept scores highest, the next highest is the Traveling Capture Net, II-1B and the Traveling Capture Net plus Impact Platform, II-1C. These concepts are then carried forward to Phase III for further study.

In Phase III, Preferred System Selection, the three remaining concepts are investigated, principally from the systems point of view, including preliminary cost and development schedule information. A parametric evaluation based on more detailed quantitative data than used in the Phase II evaluations is conducted.

The results of the Phase III evaluations still rate the parachute concept as being more advantageous than the traveling net concepts.

However, in consideration of the fact that the entire study is conducted at the conceptual level only, and that the quantification of the evaluation procedure still depends to a large extent on the judgement of the evaluators, it is concluded that the final ranking of the parachute and the traveling net concepts should be viewed as very close rather than a clear cut mandate for the parachute.

Therefore, it is recommended that detailed system studies and operations analysis should be conducted to refine existing parameters and identify and accurately analyze additional ones required for conducting evaluations beyond the conceptual level.

The parachute system effort would begin with analysis and trade-off studies to optimize parachutes with respect to aerodynamic configurations, materials and construction. A parachute installation would be incorporated in the initial design of a specific RPV to determine its effects on the size, weight, performance, and cost of the RPV.

The traveling net system(s) would be defined to provide detailed design definitions for the net assembly, the energy absorbing system, and the frame work (stanchions, etc.) with respect to joints and connections, materials, erecting, dismantling, actuation, and power supply requirements. Truck modification design details for accommodating the traveling net system would be required. Detailed weights, cost data, and operational requirements would be outputs of the defined studies.

For the parachute and traveling net systems terminal guidance trade-off studies should be conducted to determine the most suitable system for each. Ground support equipment related to the recovery systems should be identified and technical descriptions provided.

2.0 OPERATIONAL CONCEPT

The primary consideration in the evaluation of a Mini-RPV recovery system is the environment in which the system will be operated. The system must fit into the current structure of the Army, and be operated in a tactical environment by readily available officers and enlisted personnel. The following is a summary of the operational concept for the use of Mini-RPVs within the Army, with emphasis on the recovery system.

The RPV platoon is organic to the Combat Electronic Warfare Intelligence Battalion (CEWIBn), Division (proposed). The platoon functions under the staff supervision of division G2 or brigade S2. The platoon is composed of five organic sections normally deployed as follows:

(1) One section attached to each of the three brigades.

(2) One section attached to division artillery

(3) One section in general support of the division

Each RPV section is composed of a Ground Control Station (GCS) and a Launch and Recovery Team (L/R Team). Each RPV section is capable of operating independently and of receiving missions, launching aircraft, obtaining required data, disseminating the information, recovering the aircraft, and performing required organizational maintenance. The RPV section leader advises on the employment of RPVs and responds directly to the supported commander's requirements.

Deployment of the RPV section is made in close coordination with the supported unit. The GCS-to-RPV line-of-sight is critical. The GCS is located so as to ensure maximum navigation and target location accuracy. If not colocated with the L/R team, the GCS will be in line-of-sight of both the primary and secondary launch and recovery area. The RPV Section will be located in the proximity of other units in order to provide for its security. Launch and retrieval sites are not necessarily colocated, but they are selected according to the tactical situation. The retrieval site is a clear unprepared area approximately 300 meters in diameter, with the nearest 15-meter-high obstacle located outside the recovery area.

The RPV is preprogrammed to return to the primary recovery area. If the tactical situation requires relocating the recovery site to the secondary area, the GCS will direct the

RPV to the new site. When this RPV returns to the recovery area, the GCS directs the RPV to its glide path, or pre-recovery maneuver, until control of the RPV is obtained by the recovery system. If the recovery is aborted, the GCS directs the RPV into a new recovery attempt. Maximum use is made of the mobility of the recovery system. After recovery, the RPV is quickly retrieved and removed from the recovery area for maintenance and turnaround. Unless immediate reuse is required, the recovery system is removed from the area to minimize the possibility of its position being compromised.

Organizational maintenance of the recovery system is performed by personnel organic to the RPV section. Maintenance beyond the organizational capability is accomplished by direct support (DS) maintenance units operating in the forward area.

3.0 STUDY GUIDELINES AND CRITERIA

3.1 Introduction

The study guidelines discussed below consist of a review of the stipulations made in the study contract (DAAJ02-76-C-0048) and notes added to cover deviations and for clarification.

3.2 Stipulations from the Contract Statement of Work and Notes

Stipulations taken from the study contract are quoted below:

"1. The systems, whether totally airborne, or ground based, or a combination of both, shall be capable of recovering a fixed-wing RPV of the same general configuration as the "Aquila". It shall be a swept wing, pusher propeller RPV with a weight range of 120 to 200 pounds with recovery velocities of 45 to 70 knots. Deceleration forces during recovery shall not exceed 6 g fore and aft, 6 g vertical, and 3 g lateral.

2. The weight of the on-board portion of the system shall not exceed 7% of RPV gross weight and shall not adversely affect the aerodynamic or sensor performance of the RPV during the data collection portion of the mission.

3. A ground based system, if required, shall provide for tactical employment from unimproved locations in the forward battle area (approximately 2-5 km from the Forward Edge of the Battle Area (FEBA). The system shall be transportable by a vehicle no larger than the M135 2-1/2-ton truck. It should require a maximum of four men no more than one hour to unload the system from the transport vehicle, completely erect it at the recovery site, and make it operationally ready to recover the RPV; and no more than 30 minutes to dismantle it from a ready condition and load it on the transport vehicle.

4. The system shall provide for recovery in 20-knot winds with 10-knot gusts, and must be able to accommodate shifting wind directions (90 degrees through 180

degrees wind shifts in 5-minute intervals as a minimum).

5. The system shall provide for recovery within a 300-meter circle or a 215-meter by 300-meter-rectangle, with obstacles 15 meters high directly outside the recovery area.

6. During recovery operations, the system shall have minimum detectability to radar, acoustic, optical and electronic sensors.

7. Loss of or substantial damage to a complete RPV and sensor package caused by the recovery operation shall not exceed one per 100 missions. Normal damage caused by the recovery operation shall be estimated.

8. The system shall be capable of operation worldwide as defined in MIL-STD-210B."

Contractor's notations related to the above paragraphs are as follows:

Note 1 A three-view of the Aquila (XMQM-105) RPV is shown in Figure 1. The deceleration forces during recovery were changed to: 12 g fore and aft, 12 g vertical, and 12 g lateral by cognizant U.S. Army personnel.

Note 2 No change

Note 3 Additional study criteria attached to item 3 include:

(a) The recovery system gear should create minimum encumbrance to the transport vehicle while traveling to and from the recovery area.

(b) The deployed recovery system should be as mobile as possible to be able to meet the wind-shift requirement, and, if possible should be able to run for short distances with the recovery system deployed. The corollary to such criteria is: The recovery system installation shall not depend on stakes driven in the ground, nor guy lines secured by "dead-men".

(c) "Prepreparation", meaning appreciable advanced work to prepare a site for a recovery system, is undesirable. "Preparation", meaning limited effort to improve a site, is permissible.

Note 4 The effects of gusts which largely involve the dynamics of the RPV and the performance of the terminal guidance are not addressed in this study.

Note 5 The 300-meter-circle is used to define the recovery area throughout the study.

Note 6 No change

Note 7 The assessment of possible damage to an RPV during the recovery operation is handled statistically in the evaluation sections of this report (Section 10.0 and 12.0).

Note 8 The principal atmospheric criterion used in the study is a hot day condition of 4,000 feet altitude, 95°F. This set of conditions, shown in terms of standard and hot day atmospheres in Figure 2, correspond to increases in the velocities from 45 to 50 knots and 70 to 78 knots, respectively, for the 120-pound and 200-pound RPVs. The energy level increase is approximately 24 percent over sea level standard conditions.

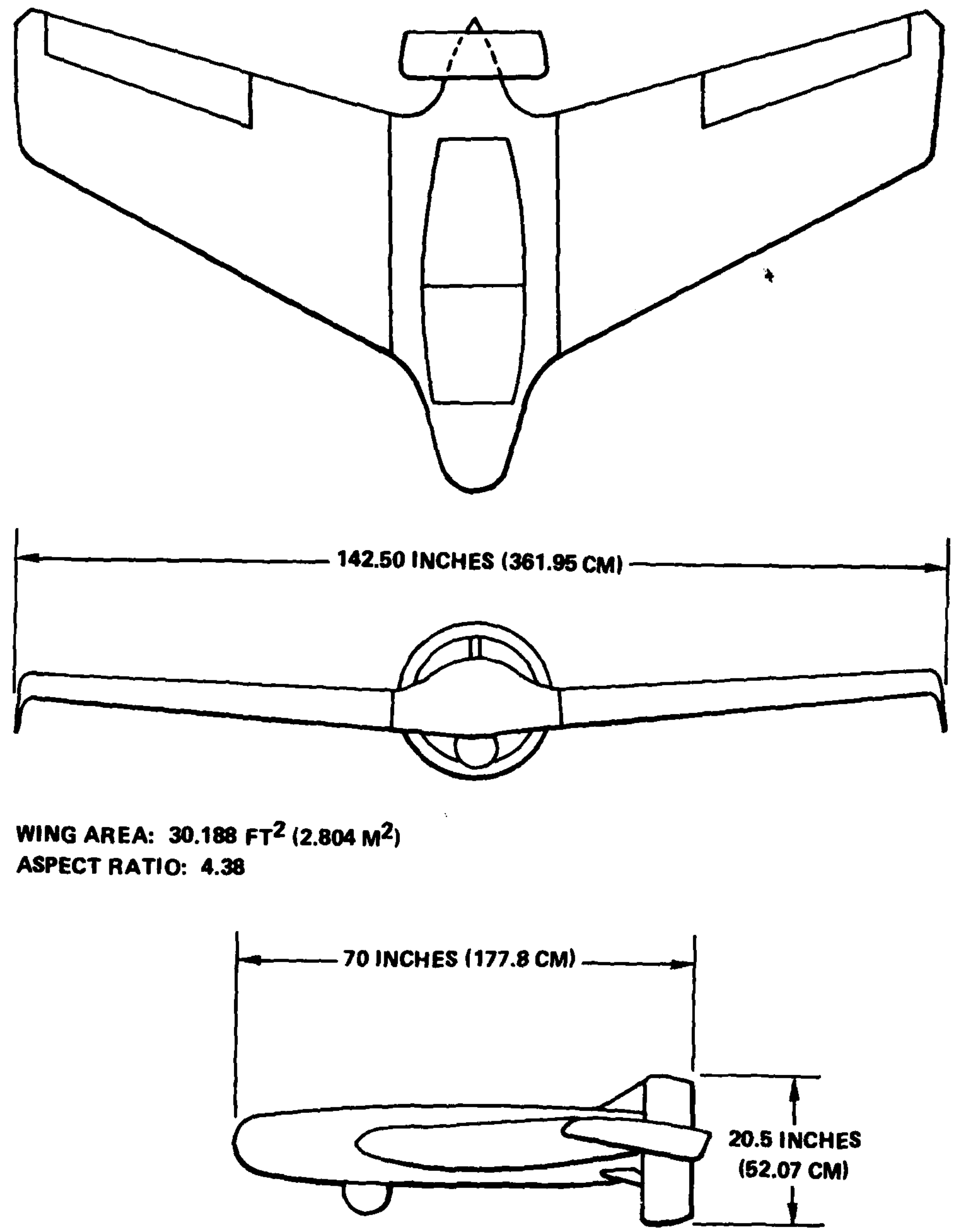

Figure 1. U.S. Army/Lockheed Aquila, XMQM-105 RPV

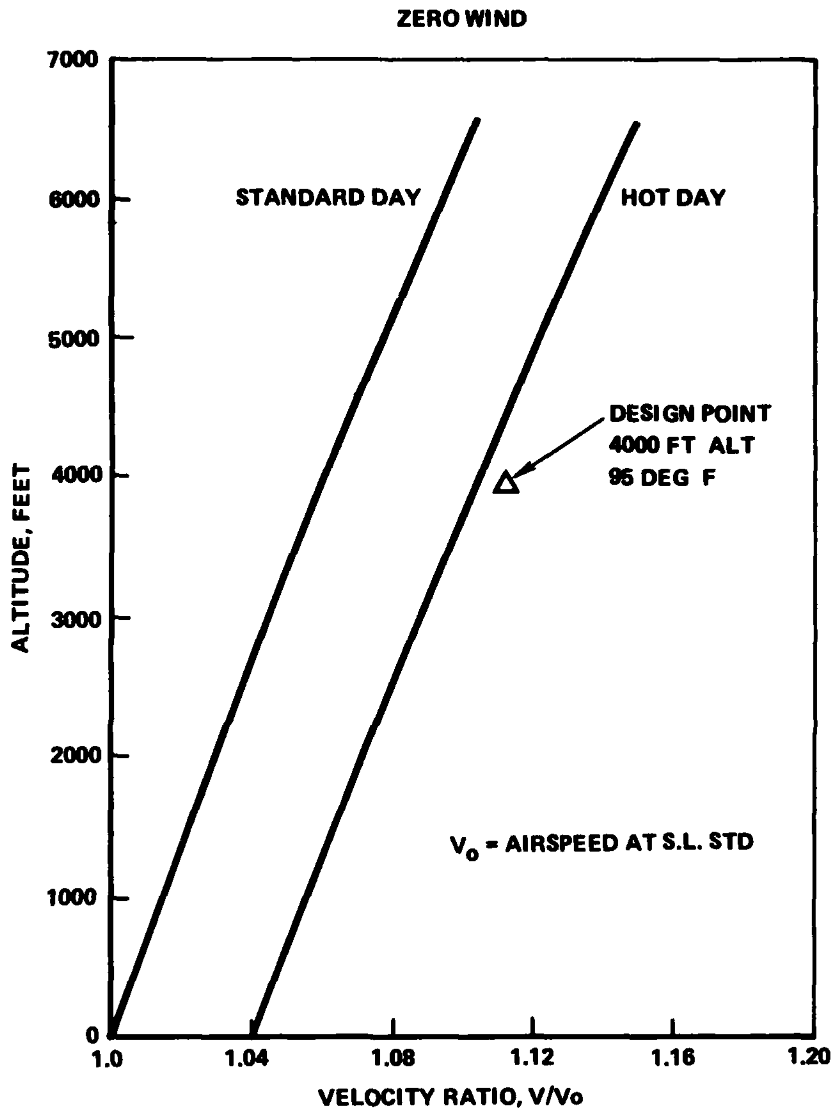

Figure 2. Altitude/Temperature Criteria for Mini-RPV Recovery

4.0 BASIC RECOVERY SYSTEM CONSIDERATIONS

4.1 Recovery Area Approach Paths

The requirement for recovering Mini-RPVs within a 300-meter circle surrounded by a hypothetical peripheral obstacle 15 meters high (Section 3.0) has general implications for the placement of the guidance system.

In the context of manned aircraft, the obstacle height specified for take-off and landing is a performance parameter. Actual safe operating procedures require that comfortable clearance margins over the specified obstacle height be maintained.

For the Mini-RPV recovery area in world-wide operations, the 15-meter obstacle can conceivably be real, as well as a performance parameter.

In Figure 3, the recovery approach geometry is shown to scale with respect to the landing area dimensions and locations for the recovery system. The typical geometry depicted applies to the concepts where the Mini-RPV approaches down a more or less normal flight path to impact the recovery device which then usually decelerates the RPV in a horizontal distance of about 50 feet or less. As will be seen later, the situation in Figure 3 will apply to over half of the recovery concepts investigated in this study. The remaining concepts are treated individually with respect to the recovery approach as they appear in the following text.

For the case of no physical obstacles at the approach edge of the 300-meter area, a 3-degree flight path (Figure 3) terminating at the impact point of a particular recovery device will be assumed. The approach distance, ℓ_a, is a function of the 3-degree flight path angle and the recovery device target point, h_1 feet above the ground.

If we temporarily assign a value of 20 feet for h_1, the approach distance, ℓ_a, is 557 feet or 65 feet beyond the mid-point of the 300-meter recovery area.

For the case of actual physical obstacles, such as trees 15 meters in height, and allowing an additional 15-meter window height (A.C.), the maximum flight path angle would be 8 degrees, which becomes a matter of accommodating among RPV, terminal guidance, and the capability of the recovery device. The RPV flight times from the obstacle to impact with the recovery device are, in this example: 4.2 seconds for the 200-pound RPV at 78 knots, and 6.6 seconds for the 120-pound RPV at 50 knots. Thus the time for corrections would be brief. The width of the window at the 15 meter obstacle (View A) is assumed to be 15 meters, thus providing a 15 by 15 meter window.

The steeper flight path angles can of course be reduced by moving the recovery target point further down field. The maximum distance, ℓ_a, is assumed to be 269 meters (884 feet) allowing for a 100-foot back-stop distance for recovery equipment (Figure 4).

In this case the time from over-the-obstacle to the impact point is approximately 5 seconds for the 200-pound class RPV, and about 8 seconds for the 120-pound class RPV. Thus, the decision to abort must be made and action taken in time to clear the recovery system and the 15-meter obstacle at the far end of the recovery area. A criterion for abort could conceivably be when the RPV appeared at any edge of the 50 by 50-meter approach window.

An overall operational problem associated with the landing area exists where the recovery system must be placed some distance from the remainder of the ground equipment. Since the exact physical makeup of the landing area for world-wide deployment of Mini-RPV sections is not defineable, it may be logically assumed that conditions will sometimes be unfavorable. In this connection there will be occasions where the recovery unit will have to be placed, for example, over 600 feet opposite from cover available to obscure the remainder of the vehicles and ground equipment with rough terrain in the area between.

Recovering the RPV in up to 20-knot winds would theoretically allow moving the recovery device closer to the approach edge of the area. However, depending on a wind to hold steady at a given velocity involves considerable risk. It would probably be better to leave the recovery device in position for no wind and increase RPV power to maintain the equivalent of a no-wind flight path. Such a procedure would probably be more compatible with some terminal guidance systems.

The above described recovery situations are at best nominal, and are intended to typify the geometry of the recovery area. Individual recovery and guidance system combinations and local topography will undoubtedly modify, to some extent, the assumptions of Figures 3 and 4.

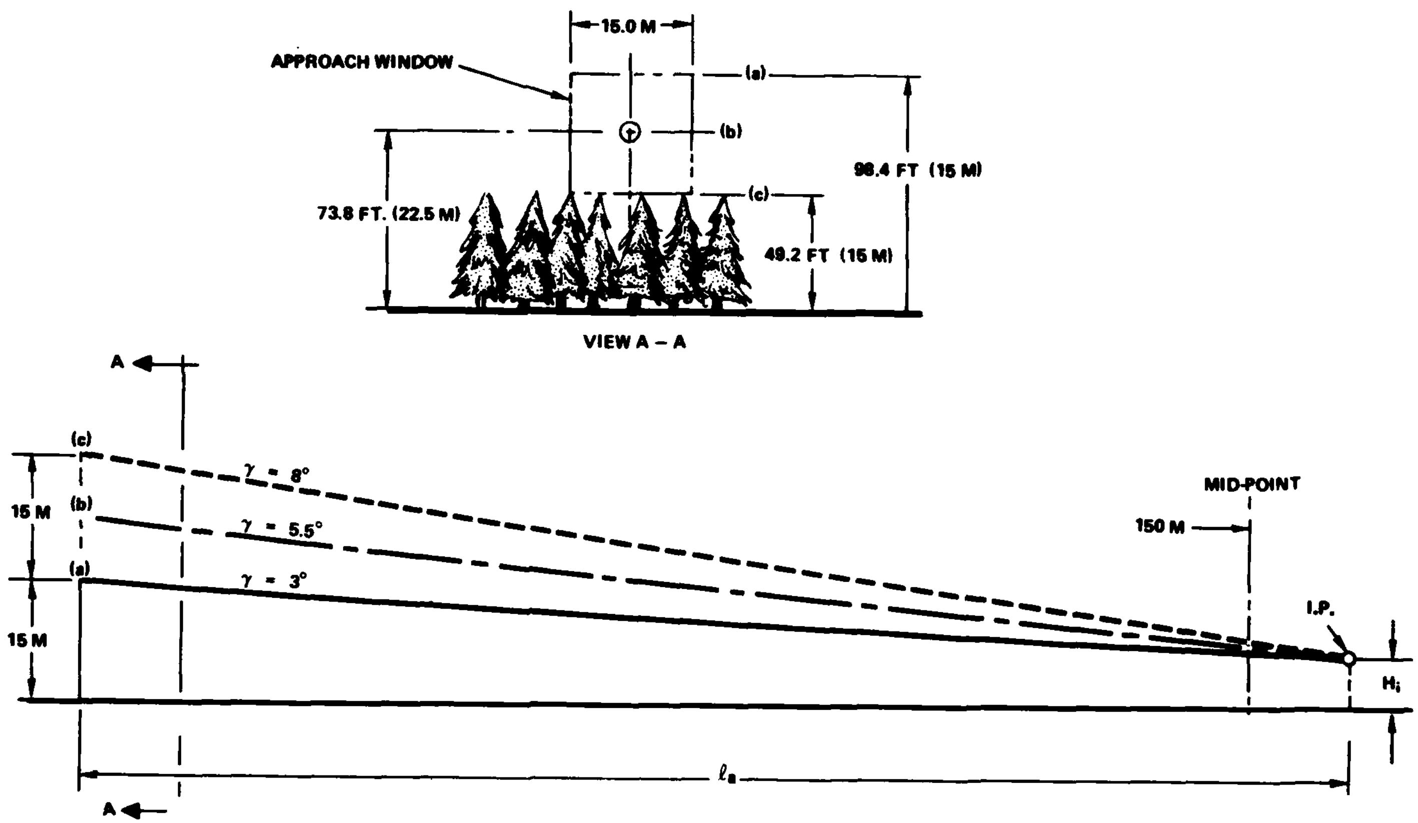

Figure 3. Typical Approach Segment, Recovery Area

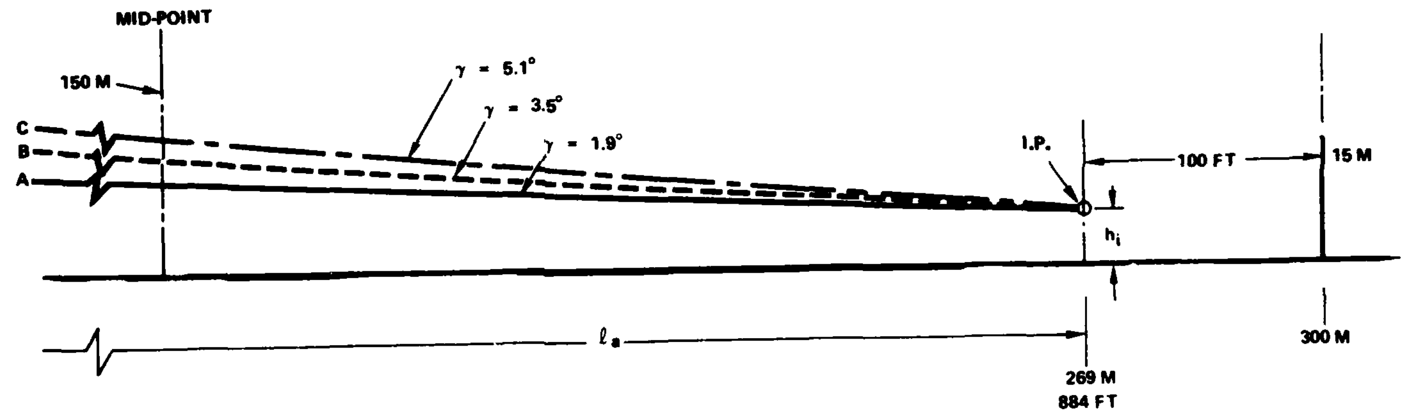

Figure 4. Maximum Approach Segment, Recovery Area

4.2 Recovery Kinetics

The subject of recovery is inextricably involved with the phenomena of impact to various degrees. Even the RPV touching down to a landing on a landing gear encounters impact in slight degrees. An RPV recovered by parachute, finally impacting the earth, is an all out case in point, and recovery by means of a net involves impact in multiple forms.

Strangely enough, one of the subjects not yet completely understood, in so far as making accurate analytical predictions is concerned, is the behavior of impulsive forces acting for a very short time interval during which neither the value of the force at any instant, nor its law of variation is known (Reference 1).

In order to circumvent this apparent theoretical impasse in determining impulse forces for preliminary investigation purposes, an assumed load factor, η, may be declared as a design condition from which a constant force, F, is determined as $F = W\eta$, where W is the weight of the impacting body.

The principal equations and computer programs used for the cursory kinetic computations of this study are discussed below.

4.2.1 Horizontal Deceleration. In the recovery situation where the body (RPV) decelerates horizontally from a given velocity to zero velocity, assuming a constant retarding force level thrust makes possible the use of simple kinetic equations to determine distance (stroke) and an average time total time to decelerate. Such procedure represents ideal conditions and is therefore baseline information. Test experience is needed in most cases to determine the actual force/time patterns that occur during the decelerating stroke.

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1. ANON, PROPOSAL FOR A PHASE I DEVELOPMENT PROGRAM OF THE GYRO-SAIL AERIAL DROP DELIVERY SYSTEM (GADDS) FOR THE PRECISE, OFFSET DELIVERY OF CARGO OR WEAPONS, TRA, San Diego, Ca., Report No. TRA 29572-1, 1 September 1965.

One basic relationship that can be used to estimate distance and time to decelerate is the familiar expressions:

Work = change in kinetic energy

or

$$F\ell = 1/2\frac{W}{g}(V_1^2 - V_o^2) \tag{1}$$

Where

F = Force, lb = $W\eta$
ℓ = distance to decelerate, ft
W = weight, lb
η = load factor or acceleration, g
V_o = initial velocity, ft/sec
V_1 = final velocity, ft/sec
g = gravitational constant

With the final velocity = 0, which is the case with RPV recovery, equation (1) can be simplified by eliminating one term and the subscripts for velocity

$$F\ell = 1/2\frac{W}{g}V^2 \tag{2}$$

or

$$\ell = 1/2\frac{W}{g}V^2/F \tag{3}$$

The weight term can be eliminated by writing equation (2) as

$$W\eta\ell = 1/2\frac{W}{g}V^2$$

and

$$\ell = \frac{V^2}{2g\eta}$$

or

$$\ell = \frac{V^2}{64.4\eta} \tag{4}$$

Thus, for cases in this study where the motion is horizontal, or nearly so, such as for capture net recovery, the distance for the RPV to decelerate can be determined as a function of the velocity at impact and the design load factor.

A typical example of the difference between the ideal computations discussed above and a real-world case is illustrated in Figure 5.

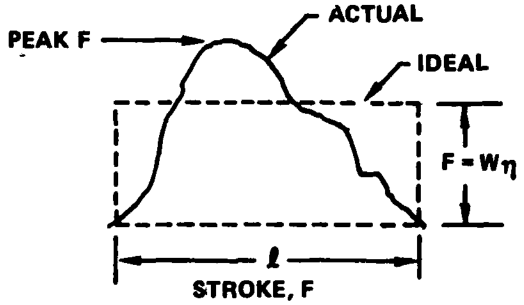

Figure 5. Comparison of Ideal and Actual Energy Absorption Curves

A set of curves such as shown in Figure 6 presents ideal distance to decelerate vs deceleration in g ($=\eta$). The average time to decelerate can be estimated from

$$t = 2\ell/v \tag{5}$$

As shown in Figure 6, the stroke ℓ was determined by either equation (3) or (4), which assume a constant retarding force applied throughout the stroke. The work done (kinetic energy absorbed) is represented by the area of the Y rectangle, F x ℓ. In practice the actual performance curve, as measured, could look like the irregular curve above. The total area under the "actual" curve would be identical to that of the ideal rectangle, since the same amounts of energy were absorbed in both cases. However, the peak F in the actual case represents an appreciably greater instantaneous deceleration (load factor) than the ideal, or average. The peak load(s) for the actual case could, in most instances, be reduced by further development of the energy-absorbing system. However, it may be found that the instantaneous peaks, though not desirable, are not particularly detrimental.

4.2.2 Vertical Deceleration. For vertically descending bodies (RPV) the equations above are modified to account for the potential energy of position of the body.

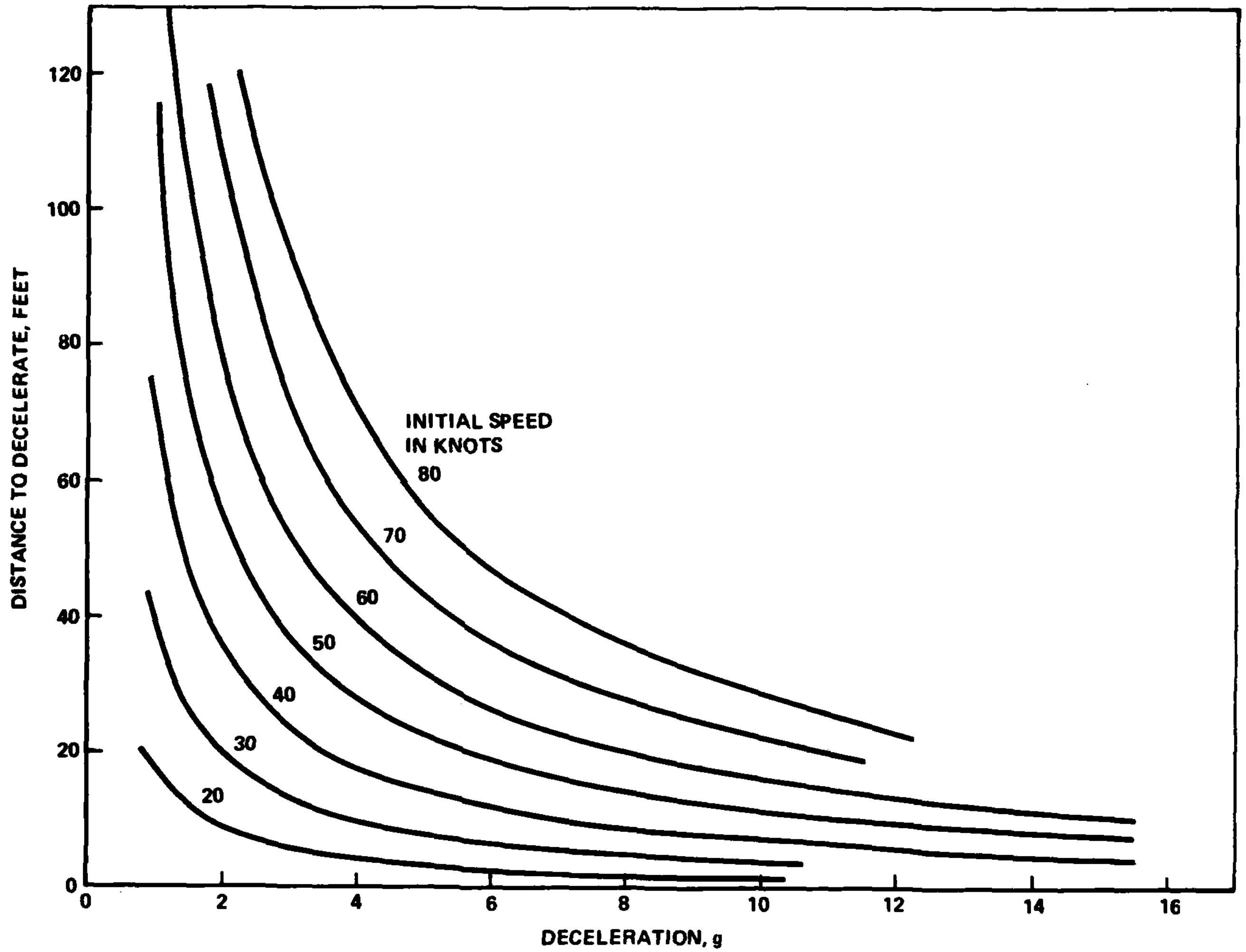

Figure 6. Ideal Distance to Decelerate to V = O vs. Deceleration Rate in g

Work = KE + PE

or

$$Fh = 1/2\frac{WV^2}{g} + Wh \tag{6}$$

From which:

$$h = 1/2\frac{WV^2}{g}/(F-W) \tag{7}$$

or

$$h = \frac{V^2}{64.4}/(\eta-1) \tag{8}$$

where h = vertical stroke, ft

It is seen from equation (8) that the higher the design load factor, n, the less effect it has on the stroke, h. At n = 12, the difference is about 10 percent.

The ideal energy-absorbing stroke for an RPV descending at 20 feet/second, where the design load factor is 12, amounts to

h = 0.565 ft = 6.78 in.

It is interesting to note that the stroke required for a given load factor (deceleration) is independent of weight. Therefore it is the same for a Mini-RPV as for a large vehicle of any weight. This fact penalizes the Mini-RPV since the stroke of an energy absorbing device is disproportionate to the size of the vehicle.

Variations of equations (7) and (8) are used in the case of a body being propelled upward (subsection 7.2.4).

4.2.3 Miscellaneous Equations

- The standard "Impulse = Change in Momentum" equation:

$$Ft = \frac{W}{g}(V_1-V_o) \tag{9}$$

is used in this study (subsection 7.7.2) where it appeared convenient to do so. Equations (4) and (5) can likewise be derived from Equation (9).

- The principle of the Conservation of Momentum, expressed in terms of the particular need, is:

  "Momentum of RPV before impact = momentum of the total system after impact".

  or

  where the RPV impacts a body at rest:

$$m_1 V_o = V_1 (m_1 + m_2) \tag{10}$$

  or

$$V_1 = \frac{M_1 V_o}{(m_1 + m_2)}$$

  where:

  m_1 = mass of RPV = W_1/g

  m_2 = mass of body impacted = W_2/g

  V_o = velocity of RPV at impact, ft/sec

  V_1 = common velocity of system, ft/sec

- Centrifugal Force

$$r = V^2/gn \tag{11}$$

  where

  r = radius, ft

  V = tangential velocity

  n = radial load factor, g

  g = gravitational constant

- Energy Height

$$he = \frac{V^2}{2g} \tag{12}$$

Computer Analysis

Teledyne Ryan Aeronautical in-house programs were employed for parachute trajectory studies in subsections 7.2.2, 7.9.3 and 7.9.4.

5.0 DATA SURVEY

5.1 General

A survey was conducted to seek available information on concepts, designs, and other data pertinent to the recovery of RPVs in the 120-pound and 200-pound weight class for recovery speeds up to 78 knots.

The survey, discussed in the paragraphs following, consisted of four major elements:

- Literature Search
- Letter of Solicitation
- Patent Search
- Magazine Advertisement

5.2 Literature Search

DDC Bibliography. The usual first step in literature searches in Aerospace, a request for a report bibliography from the Defense Documentation Center, was taken for the Mini-RPV Recovery Study. The resulting bibliography is:

- Title: RPV Recovery Systems
- Search Control No. 045328 (S)
- No. References: 229

In an initial screening of the 229 documents, 51 were selected as most likely prospects pertaining to RPVs. A second screening reduced the list to 19 documents containing possible benefits to the study of Mini-RPV recovery.

In-House Sources. In addition to the DDC bibliography, available TRA in-house literature on RPV recovery was reviewed. This included reports, technical papers, proposals, intercompany communications and accumulated work sheets held by individuals.

Typical of the reports are References 2 and 3. Technical papers include the complete roster of papers from the AIAA 5th Aerodynamic Deceleration Systems Conference, Albuquerque, New Mexico, November 1975. Other examples include supportive proposals (References 4, 5, and 6) plus numerous in-house communications.

5.3 Letter of Solicitation

A Letter of Solicitation requesting concepts and ideas applicable to the recovery of Mini-RPVs was mailed to organizations selected because of Mini-RPV and/or related recovery system interests. The distribution and results of this part of the data survey are listed below.

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2. Mason, J. S., RECOVERY ELEMENT TRADE-OFF ANALYSIS USAF AQM-34V (ABIAS), TRA, San Diego, Ca., Report No. TRA 25566-33, 13 August 1976.

3. Childers, G. C.; Hamrick, B. R., FINAL TEST REPORT FOR THE XMQM-34D AIR BAG GROUND DROP IMPACT TEST, TRA, San Diego, Ca., Report No. TRA 29242-1, 22 October 1973.

4. ANON, U.S. NAVY SHIP DEPLOYABLE TACTICAL RPV SYSTEM, TRA, San Diego, Ca., Report No. TRA 29308-15, 19 February 1974 (Model 262) (C).

5. ANON, U.S. ARMY RPV SYSTEM TECHNOLOGY DEMONSTRATOR PROGRAM, TRA, San Diego, Ca., Report No. TRA 29308-24, 30 August 1974, (Little 'r'), (C).

6. ANON, PROPOSAL FOR HIGH-ALTITUDE PLATFORM STUDY, TRA, San Diego, Ca., Report No. TRA 29270-16, 20 May 1970.

	Solicitations	Replies	Contributions
U.S. Industry	20	12	6
Foreign Industry	11	2	0
U.S. Government Agencies	9	6	6
Universities	2	2	1
	42	22	13

It should be noted that the above number of written contributions of U.S. industry and U.S. government agencies listed do not cover information received through telephone conversations with TRA, or direct communications on the subject of Mini-RPV recovery between government offices.

Contributions are identified in the technical section of this report as reference material.

5.4 Patent Search

A U.S. Patent Office search under the title "Remotely Piloted Vehicle (RPV) Recovery Systems" was initiated by the legal department of TRA.

Thirty-nine patents were listed. Chronologically the patents dated from June 17, 1919, through February 17, 1976.

The patent search revealed little that directly aided the quest for Mini-RPV Recovery Systems. It did, however, establish historical background for some of the latter day concepts. In this context patents are referred to in subsections 7.7, 7.8, 7.10 and 7.11 of this report.

5.5 Magazine Advertisement

The final element of the data survey was the placing of an advertisement in the classified section of a magazine to solicit Mini-RPV recovery concepts and ideas.

The advertisement was purposely directed away from the world of Aerospace by placing it in Popular Science magazine. The ad appeared on Page 222 of the October 1976 issue of Popular Science. This particular solicitation was processed in two stages; the ad, in effect, invited interested parties to inquire about the details of submitting a concept or idea before actually submitting any information on the subject. An instruction package, including requirements and ground rules, was forwarded to those who responded to the ad. In this way, the inquirer was furnished more information on which to base a decision to respond than could logically be included in a classified ad.

Statistics on the magazine advertisement are:

Inquiries	Instruction Packages Forwarded	Submittals
52	43	13

(Note that nine inquiries were received beyond an extended dead line.)

The 13 submittals are categorized follows:

Inadequate

(1) 21 words, no diagrams
(2) 18 words, no diagrams
(3) 28 words, no diagrams
(4) 70 words, no diagrams
(5) modified regenerative ram-jet V/STOL, no diagrams

Moderately Substantial

(6) A rudimentary traveling net
(7) Tail-sitting recovery for Aquila
(8) A form of wires and I [illegible].
(9) Truck-mounted high wire trapeze
(10) Rectangular bag filled with polystyrene foam aided by energy dissipative lines and weights

Substantial

(11) Stowed rotor fitted to Aquila
(12) Pivoted net
(13) Wire and I.P. and retro rocket

That material submitted as a result of this magazine ad, and judged to be useful to the technical portions of this study, is contained in the reference material.

5.6 Survey Overview

In view of the relative newness of the subject and very limited scope of Mini-RPV recovery experience, the data survey was probably as productive as could be expected at this time. Six out of twenty-seven concepts are related to the data survey. These are concepts I-4A, I-5A, II-4B, II-4D, II-8A, and II-8B, which are identified in Section 6.0 (Table 1).

Newness is partly evidenced by the low capture rate of the DDC literature search (about 8 percent), which generally rates much higher where a technology and its nomenclature are well established. Also, the relatively low number of replies to the magazine ad indicates that the world of uninhibited inventors has not really warmed up to the subject of Mini-RPV recovery.

The scope of this subject, as far as direct solicitation to industry is concerned, is limited to a very few U.S. and foreign aerospace firms, most of whom may have proprietary interests that would preclude revealing new and innovative concepts.

The true measure of productivity of the survey will be made in terms of the number of worthy Mini-RPV recovery concepts that emerge after this report is published.

6.0 RECOVERY CONCEPT CATEGORIZATION

6.1 Introduction

In order to investigate a series of propositions such as presented by the presently known and some newly identified Mini-RPV recovery concepts, a system of nomenclatures is needed.

For this purpose the recovery concepts identified for this study are categorized in Table 1. The concepts are divided into two general groups:

Group I - Surface-Impact

Group II - Above-Surface-Recovery

In the tab listing of Table 1 the basic concepts are identified as I-1 through I-5, and II-1 through II-9, totaling fourteen in all.

The four columns, A, B, C, and D, include the basic and/or spin-off concepts amounting to 27 total. It will be noted that where no spin-off concepts are identified, the basic concept designation is repeated in Column A. (Example: I-1 Runway and II-3 Rotary/Carousel). In this way, the total concept spectrum for study appears within Columns A, B, C and D.

The relative newness of the Mini-RPV and associated recovery schemes does not yet afford a standard set of nomenclature; therefore Table 1 is largely improvisation. In this connection, it will be noted that some of the concepts would fit in either of two categories. For instance, the fabric rotor, I-2C, because it is made of fabric and is intended to glide, was put in the parachute category. But it could also qualify as a stowed rotor. Likewise the wire plus chute plus I.P., II-7C, could be retitled "chute plus wire plus I.P." and put under the parachute category, II-4.

Also, data on capture nets received very late in the study process are not included in Table 1 because they represent a new set of nomenclature for essentially the same net concepts listed. However, the late comers are identified, together with the nets shown in Table 1, in Section 11.0 of this study.

TABLE 1. RECOVERY CONCEPT CATEGORIES

		A	B	C	D
GROUP I SURFACE IMPACT	I-1 RUNWAY	RUNWAY	---	---	---
	I-2 PARACHUTE	NONGLIDING, GLIDING	TRANSFERRED	FABRIC ROTOR	---
	I-3 RETRO ROCKET	RETRO-ROCKET	---	---	---
	I-4 STOWED ROTOR	• STOWED ROTOR	---	---	---
	I-5 SPIN RECOVERY	• SPIN RECOVERY	---	---	---
GROUP II ABOVE-SURFACE-RECOVERY	II-1 CAPTURE NET	FIXED	TRAVELING	TRAVELING + I.P.	INFLATABLE FRAME
	II-2 INCLINED RAMP	FRICTION	FRICTION + AUX. DECL.	---	---
	II-3 ROTARY (CAROUSEL)	ROTARY	---	---	---
	II-4 PARACHUTE	MARS	• WINCH-DOWN	DECL. CHUTE + I.P.	• IN-FLIGHT HOOK-UP
	II-5 AERIAL TRACK	AERIAL TRACK	---	---	---
	II-6 'U' CONTROL	'U' CONTROL	---	---	---
	II-7 ARRESTING WIRES	HIGH WIRE TRAPEZE	WIRE + I.P.	WIRE + CHUTE + I.P.	---
	II-8 TETHERED AERIAL	• AEROSTAT	• WIND-DEPENDENT	ROTARY WING	---
	II-9 BRUSH ATTENUATOR	BRUSH ATTENUATOR	---	---	---

• CONCEPTS ATTRIBUTABLE TO DATA SURVEY

6.2 Concept Glossary

A brief definition of each concept listed in Table 1 is as follows:

GROUP I - SURFACE IMPACT

Surface Impact recovery implies that the Mini-RPV comes to rest on, and is retrieved from, the ground.

Runway I-1A

A conventional landing mode in which the RPV approaches along a predetermined glide path, flares, touches down, and rolls or skids to a stop.

Parachute I-2

Parachute recovery concepts terminating in ground impact with impact-attenuators as options.

I-2A Gliding/Nongliding

Nongliding chutes are defined here as those for which no special provisions are included to induce gliding, and the L/D ratio does not exceed 0.6. Gliding chutes for surface impact refer to flexible fabric wing (Hi-glide chutes) with L/D = 2.5 to 3.0.

I-2B Transferred

A concept in which a parachute is transferred from the ground on a rocket-powered line system to engage another line/grappling-hook system trailed by the RPV, after which the chute deploys and lowers the RPV to the ground.

I-2C Fabric Rotor

A concept in which a fabric rotor, stowed in the RPV in a manner similar to a conventional chute, deploys in a two-stage spin-up sequence to form a fabric auto-gyro rotor with variable L/D options of approximately 1.5 to 3.7.

Retro Rocket I-3A

A recovery concept employing vectored retro rockets installed in the RPV airframe. The rockets are fired at low altitudes (less than 10 feet) to decelerate the RPV from glide-path velocity to zero velocity at the ground's surface.

Stowed Rotor I-4A

A recovery concept in which a three-blade auto-gyro rotor is mounted on a pylon, extending aft of the propeller guard on the XMQM-105 Aquila Mini-RPV. Rotor blades are hinged to fold forward on the RPV, parallel to the airstream in cruise flight. A deployed rotor assumes an autorotative mode to lower the RPV in a nose-down attitude to the ground.

Spin Recovery I-5A

A concept similar to the stowed rotor, I-4, except the wings are pivoted to form a rotor for autorotative descent.

Group II - Above-Surface Recovery

Above-surface recovery group encompasses systems that leave the RPV positioned above the surface of the earth after being arrested.

Capture Net II-1

A generic term for nets that engage, decelerate, and retain an RPV.

II-1A Fixed/Articulated

A concept employing a fixed capture net secured at several points around its periphery to a fixed frame with energy absorption as a function of the elasticity of the net, attachments, and frame which generally constitutes a short energy-absorbing stroke. Mounting the net frame stanchions on pivots to provide articulation and adding external energy-absorbing devices increases its recovery capability.

II-1B Traveling Net

A net that detaches from its supporting frame by breaking temporary ties and travels out against cables restrained by energy absorbing devices.

II-1C Traveling Net Plus Impact Platform

A form of traveling net incorporating a resilient base or platform for the net-enclosed RPV to drop on to after the run-out stroke is completed.

II-1D Inflatable Frame

A type of traveling net mounted on a tubular, inflated frame of elastomeric material that collapses to form an impact platform.

Inclined Ramp, II-2

A concept that is essentially an up-hill runway made of resilient straps or ribbons stretched between frames that position the ramp above the ground.

II-2A Friction

A type of inclined ramp that depends on friction and the retarding force component of the RPV weight to decelerate the RPV.

II-2B Friction Plus Auxiliary Decelerators

A type of inclined ramp that incorporates auxiliary deceleration devices to shorten the RPV run-out distance.

Rotary Carousel II-3A

A recovery device featuring a projecting cantilever arm pivoted on a central stanchion. Capture devices such as hoops or rings, attached to the outer end of the arm, engage hooks mounted on the RPV's wing tips. Energy is dissipated as the RPV travels in a circular path around the arm's pivot point after locking onto the capture device.

Parachute II-4

A group of parachute concepts that retain the RPV above the surface of the ground after recovery.

II-4A MARS (Mid-Air Retrieval System)

A concept in which a manned helicopter, by means of a trailing boom arrangement, snares a small engagement parachute connected to the main parachute of a descending RPV. The RPV can then be reeled up and towed to its base to be lowered to the ground without damage.

II-4B Winch Down

A concept in which the RPV, with a trailing hook deployed, picks up a wire stretched between two stanchions. Attached to the pick-up wire is a length of wire terminating at the center of a resilient platform placed on the ground several hundred feet ahead of the pick-up point. The RPV is directed into steep climb after the hook-up. Near the top of its trajectory a parachute is deployed. The wire attached to the RPV is then reeled in by a winch located under the center of the platform.

II-4C Deceleration Chute Plus Impact Platform

A concept employing a drag chute intended to decelerate the RPV in a reasonably flat, low altitude trajectory onto a resilient impact platform.

II-4D In-Flight Hook-Up

A concept in which an RPV deploys a flexible fabric wing (Hi-glide chute) and the chute/RPV combination flys under RPV power at relatively low speed toward a projecting horizontal arm which ensnares the chute. The RPV then swing in a pendulum fashion and comes to rest.

Aerial Track II-5A

This concept, sometimes referred to as the "Brodie" system, is based on a long horizontal cable on which a capture device, such as a net or loops of resilient rope or tape, rides on a trolley. The RPV engages the capture device which travels the length of the cable retarded by an energy-absorbing snubber line attached to the trolley. The aerial track is closely related to the traveling nets noted above. The major difference is that the aerial track is intended for longer run-out distances and therefore lower deceleration rates.

'U' Control, II-6A

A concept which derives its name from the flight scheme in which a model airplane with wires attached to a wing tip is flown in circles by an operator holding the opposite ends of the wires at the center of the flight circle.

In the RPV recovery version a line with a weight on its end is reeled out as the RPV is commanded to fly in a circle. With proper coordination of the turn pattern, altitude, and wire length, the hanging weight can be positioned at the center of the turn as it nears the ground. Thus while traveling relatively slowly in a small circle the weighted end of the line can be picked up and secured to a winch at the base, or the pivot point, of a boom located on a land vehicle. The boom, with a hook at its end, is elevated and rotated at sufficient speed to engage the line. By reeling in the line and lowering the boom, the RPV is gradually changed from free flight to "U" Control flight. The boom is then gradually raised as its rotation is slowed and the RPV is finally left hanging on the line clear of the ground.

Arresting Wires II-7

Recovery by means of a trailing hook deployed by the RPV engaging a horizontal wire linked to an energy absorbing system similar in principle to the arresting gear on an aircraft carrier.

II-7A, High Wire Trapeze

A concept in which the RPV trails a hook and engages a horizontal wire stretched between two stanchions. The wire runs over pulleys at the top of each stanchion and leads down to energy-absorbing devices. The stanchions are high enough that after the proper amount of wire run-out has been achieved during deceleration, the RPV swing back like a pendulum to a free-hanging position a short distance above the ground.

II-7B Wire Plus Impact Platform

An arresting wire concept in which the RPV drops onto an energy-absorbing platform at the end of the wire runout. The platform construction could be similar to those suggested for the capture net impact platform of II-1C above.

II-7C Wire Plus Chute Plus Impact Platform

A recovery system in which an RPV deploys a hi-glide chute and a trailing line with a grappling hook attached.. The RPV/chute would fly under power toward an impact platform that is surrounded by an arresting wire attached to posts disposed in a circular pattern to provide an omnidirectional approach. The RPV's trailing wire would engage the arresting wire and the RPV/chute would drop on the impact platform.

Tethered Aerial II-8

Recovery systems based on relatively long, tethered vertical lines supporting various lift devices.

II-8A Aerostat

A type of recovery system involving a single line supported by a balloon. The RPV would engage the line by a hook/latch mechanism mounted on the RPV wing tips, similar to the rotary (carousel), II-3A. Another system employs two balloons to support a capture net.

II-8B Wind-Dependent

A recovery system in which the RPV deploys a hi-glide chute and a trailing line with a grappling hook attached. After the grappling hook engages an object on the ground, the RPV chute is reeled in like a kite.

II-8C Rotary Wing

A recovery system employing a turbine-powered rotary wing platform tethered by a line to a ground vehicle control station. A horizontal pole with several dangling lines is mounted to the bottom of the rotary-wing platform. The RPV then engages a dangling line, or the central tether line, by means of a wing tip hook/latch device similar to II-3A and II-8A above.

Brush Attenuator II-9A

A concept derived from the experience of free-flight model aircraft landing without damage in tall grass, grain, or weeds.

A mechanical version of the brush recovery scheme would be a series of bristles or flat stems of material like nylon or fiber glass composites representing the stems in nature. The length of the stems can be made to increase in height along the flight path. Support frames for the bristles can be made in modules and the bristles arranged to fold down flat for transport.

7.0 PHASE I RECOVERY CONCEPT STUDIES

The following Phase I studies are designed to provide an understanding of the various Mini-RPV recovery concepts categorized in Section 6.0 to the depth necessary for preliminary evaluation and selection purposes.

7.1 Runway, Concept I-1

7.1.1 General. Taking off from, or landing on a designated area is the most prevalent form of launch and recovery for land-based, manned aircraft; but in most cases it is not the preferred mode for RPVs. Two major reasons for this are: (1) the RPV has not yet been accepted as a partner in sharing runways with manned aircraft, and (2) many of the RPV military missions necessarily require operations from temporary locations in remote areas.

The field operations specified for the Mini-RPV of this study will occur in unimproved locations approximately 2 to 5 kilometers from the FEBA. This stipulation alone would appear to preclude further consideration of runway operations which may require prepreparation of the surface of the landing area; however, investigations were conducted to put the problem in perspective.

Landing distances for the two classes of RPVs under consideration to determine their relation to the recovery area dimensions will be calculated and alternatives in the form of auxiliary energy-absorbing devices to shorten the landing run will be discussed.

7.1.2 Analysis

a. Runway Landing Without Auxiliary Energy Absorbers

Landing distances over a 15-meter obstacle are estimated for the 120-pound Aquila class RPV, and the 200-pound class Mini-RPV as shown in Table 2. It is assumed that the RPVs are equipped either with a wheel-type landing gear with brakes or with skids. A coefficient of friction, μ, of 0.3 is used in the calculations. The runway is assumed to be the surface of the earth.

TABLE 2. LANDING DISTANCE SEGMENTS

$\mu = 0.3$

RPV	ℓ_a ft	ℓ_t ft	ℓ_d ft	TOTAL DISTANCE ft
120 lb, 50 Knots Meters	389	121	245	755
200 lb, 78 Knots Meters	303	294	561	1158

The approach speeds for the critical design environment of 4,000 feet altitude, 95°F, are 50 and 78 knots for the 120-pound class, and the 200-pound class RPVs, respectively. The approach flight path angle for either vehicle is based on a maximum L/D of about 9, which corresponds to a flight path angle, γ, of about 6 degrees. This approach condition could be achieved power-off if needed, or at higher angles of attack with power added. And of course, flatter approach angles could be flown with appropriate angles of attack and power combinations.

It will be noted in Figure 7 that the flight path is based on zero clearance above the 15-meter obstacle, h_o, which injects optimism in the landing distance calculations. The horizontal approach distance, ℓ_a, depends on the height of the obstacle, h_o, and the height, h_1, at which the flare-out or transition maneuver begins.

$$\ell_a = (h_o - h_1)/\tan\gamma \tag{13}$$

The height, h_1, is a function of the RPV's velocity and an assumed incremental normal load factor due to the centrifugal effect incurred during the change of the flight path direction during transition. For these estimates, a value of $\Delta\eta=0.2$ g is assumed for the incremental load factor. The radius of the transition path is determined (Reference 7) as

$$r = V^2/g\Delta\eta \tag{14}$$

The horizontal transition distance is estimated as

$$\ell_t = \cos\frac{\gamma}{2}\,(2r\sin\frac{\gamma}{2}) \tag{15}$$

The ground run-out distance, ℓ_d, is calculated by:

$$\ell_d = V^2/2\mu g \tag{16}$$

where, μ, the coefficient of friction, is assumed to be constant throughout. A further simplification in the landing distance estimates is to assume that the velocity through transition is constant and equal to the approach path speed; which would not be so, since some deceleration would occur. However, this assumption is more than offset by assuming that the touchdown speed on which ℓ_d is based is the stall speed of the RPV.

It will be noted (Table 2) that the approach distance for the smaller 120-pound RPV is longer than that of the 200-pound RPV because its h_1 height is much less.

It is also seen that the total landing distance for the faster 200-pound class RPV would exceed the 300 meter field length. The slower 120-pound vehicle would stop within approximately 76 percent of the available field length.

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7. Kuhn, R. E., TAKE-OFF & LANDING DISTANCE AND POWER REQUIREMENTS OF PROPELLER-DRIVEN STOL AIRPLANES, 25th Annual Meeting, IAS, N.Y., N.Y., NASA Pre-print, January 1957.

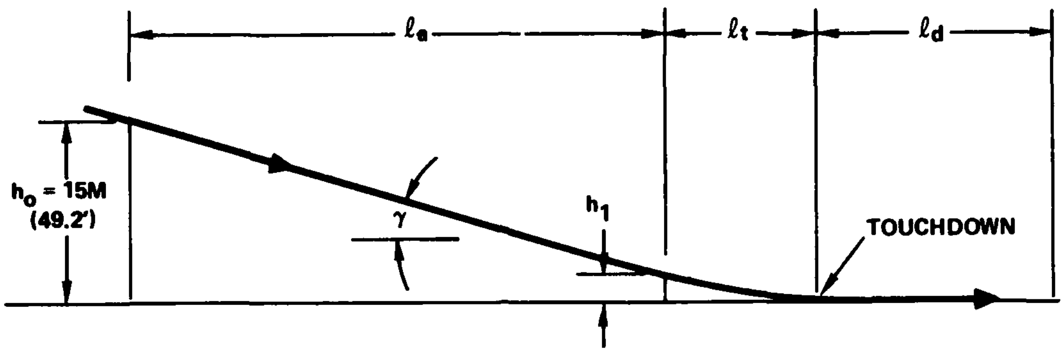


Figure 7. Flight Path, Runway Landing

b. <u>Runway Landing With Auxiliary Energy Absorber</u>

Within the context of runway landing, the most probable candidates for auxiliary deceleration would be: (1) a wire/tail hook arresting system similar to that used on aircraft carriers or (2) a barricade type net.

Figure 8 shows the effects of applying various decelerations, in terms of g, after touchdown. The run-out distance, ℓ_d, is shortened appreciably up to about 2 g, beyond which the reductions occur at a sharply decreasing rate.

Assuming a constant retarding force, the ideal run-out distances, per se, become quite short with the higher deceleration values. Estimates for the ℓ_d values are tabulated below:

	ℓ_d (ft)					
η, g	1.0	2.0	4.0	6.0	10.0	12.0
120-lb, 50-knot RPV	73	38	19	13	7	6
200-lb, 78-knot RPV	168	85	42	28	17	14

The relatively short run-out distances are a small portion of the total runway length for either type of auxiliary deceleration scheme.

An approximation of the length segments of the wire/tail-hook arresting gear type runway is shown in Figure 9 (a). The total length of 142 feet is based on a 12g run-out distance, ℓ_d, for the 200-pound class RPV. The target window height, h_1, is about 8 feet.

The barricade type runway, Figure 9 (b), is estimated to be 155 feet long, with the same ramp over-run and target-window dimensions.

A runway width of 25 feet is assumed in both cases.

7.1.3 Concept Overview. For the runway concept, the minimum airborne equipment added to the RPVs would be an extendable (as distinguished from a retractable) skid landing gear. For the wire/tail-hook scheme the tail hook installation would be added.

The runway landing without auxiliary energy absorbers involves three factors that are incompatible with the intended type of Army operations:

(1) Prepreparation of a runway which would not allow for shifting wind direction.

(2) Excessive landing distances from the 200-pound class RPV.

(3) A very large, permanent visual signature.

The runway landing scheme with auxiliary energy absorbers can provide total landing distances within the constraints of the 300-meter landing area, and could conceivably be mobilized to a great extent. However, it will involve either: (1) large moveable platforms of about 3500 to 3800 feet which must be completely mobilized to meet shifting wind conditions, or (2) combinations of smaller platforms and prepared earth surfaces. In any event, unwieldy objects with large visual signatures would result. The runway landing concept is concluded to be incompatible with the intended field operations requirement and no further evaluations will be conducted.

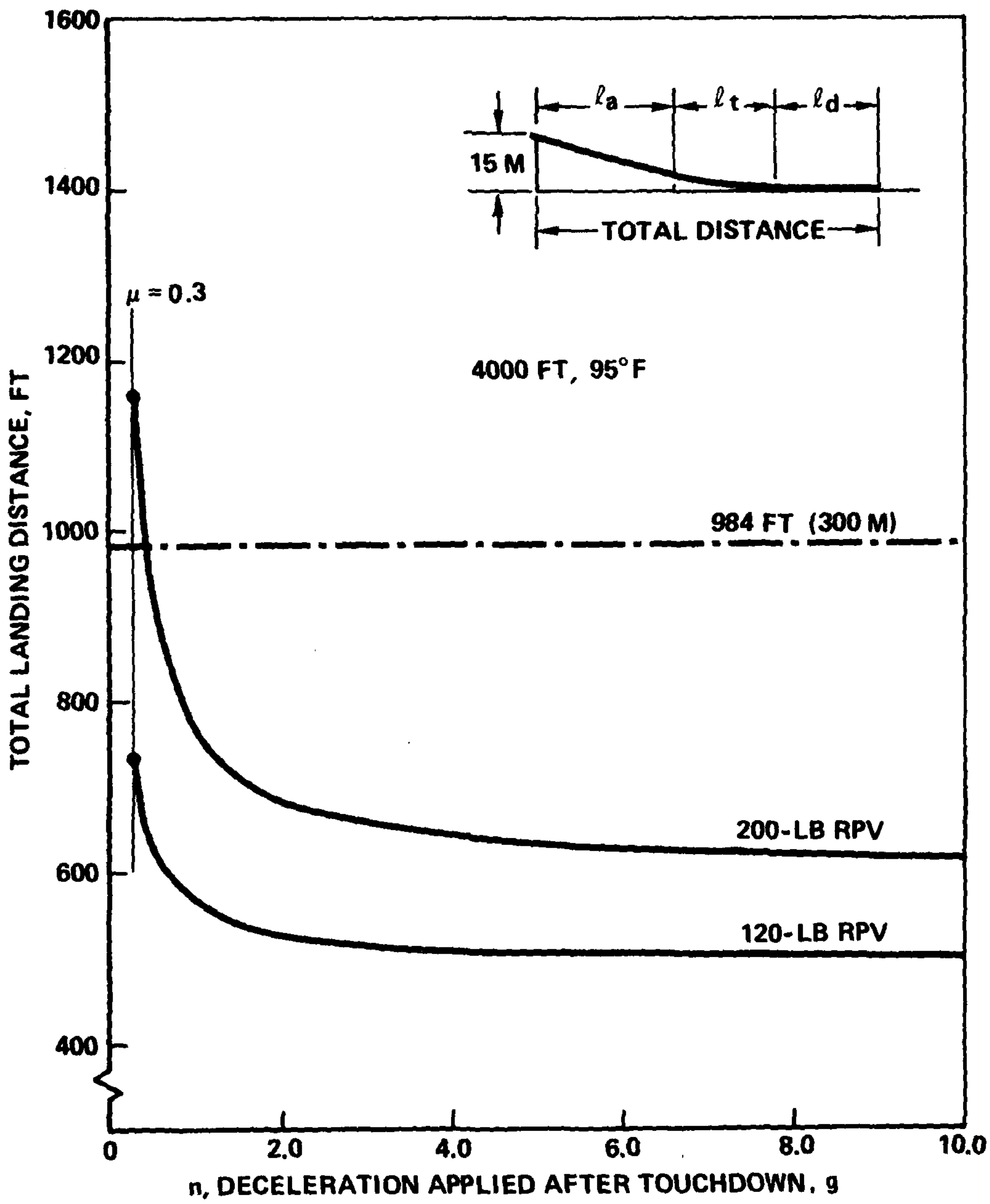
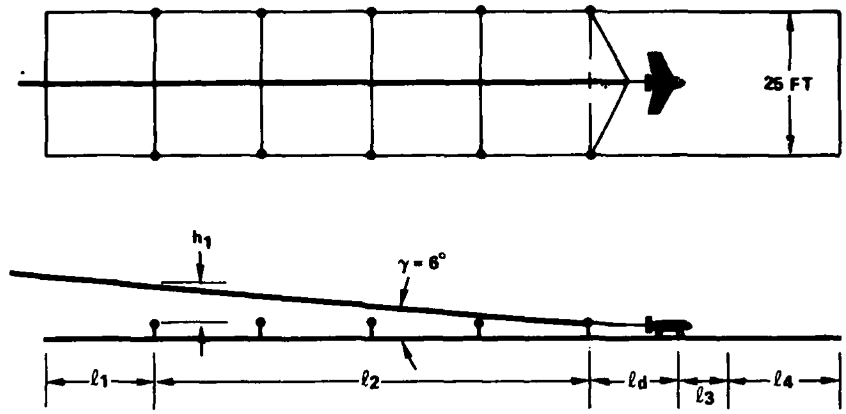


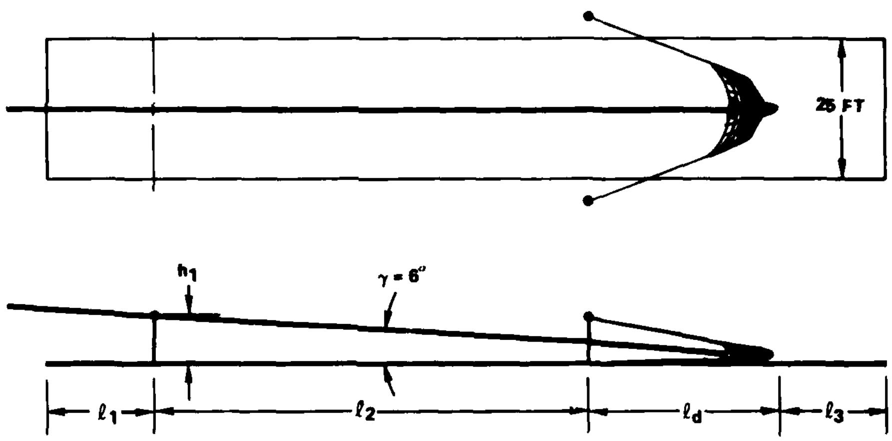
Figure 8. Landing Distances with Deceleration Aids



ℓ_1	RAMP	20 FT
ℓ_2	FIVE WIRES, 20' APART	80 FT
ℓ_3	LENGTH OF RPV/HOOK	8 FT
ℓ_d	RUNOUT DISTANCE	14 FT
ℓ_4	OVER RUN	20 FT
		Σ 142 FT

$h_1 = 8$ FT

(a) APPROXIMATE DIMENSIONS FOR WIRE/TAILHOOK TYPE ARRESTING GEAR



ℓ_1	RAMP	20 FT
ℓ_2	DISTANCE TO GIVE $h_1 = 8$ FT.	80 FT
ℓ_d	NET/LINE STRETCH + 14 FT. RUN OUT	35 FT
ℓ_3	OVER RUN	20 FT
		155 FT

$h_1 = 8$ FT.

(b) APPROXIMATE DIMENSIONS FOR BARRICADE-NET TYPE ARRESTING GEAR

Figure 9. Portable Runway Dimensions

7.2 Parachute, Concept I-2

7.2.1 Introduction The surface-impact mode has been a principal means of chute recovery for RPVs (drones) for approximately three decades. (Reference 8.)

Parachute technology encompasses an array of nominally circular chutes, including some for special purposes which can glide at an L/D ratio of up to about 1.0, and a few flexible fabric wing (hi-glide) types of more or less triangular or rectangular planform with practical L/Ds of 2.5 to 3. Several different types of parachutes including four of the flexible fabric wing are reviewed in References 9 and 10. Representative configurations of the above chute technology classifications are depicted in Figure 10.

The nomenclature for parachutes, like most other technologies that grow over a period of years, is sometimes confusing. For the nominally circular chute category, the parachutes, usually thought of as nongliding, actually tend to glide to varying degrees. However, in most cases they prefer to oscillate rather than stay in a steady-state glide. The gliding/oscillating tendency is reduced by increasing either the porosity (permeability) of the fabric, or ventilating (called geometric porosity) the chute such as in the case of the ribbon type chutes.

In this study the term "nongliding chute" denotes chutes for which no special design provisions have been made to purposely induce gliding performance. An arbitrary L/D cutoff of 0.6 is assumed for the nongliding chute category.

A limited amount of experience, some operational and some

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8. ANON, FLIGHT CONTROLLER MANUAL, USAF AND NAVY MODEL BQM-34A TARGET T.O. 21M-BQM-34A-1, NAVAIR 01-100BA4, Change 7, 1 March 1976.

9. Pepper, W. B., Maydew, R. C., AERODYNAMIC DECELERATORS - AN ENGINEERING REVIEW JOURNAL OF AIRCRAFT, AIAA, N.Y., N.Y., 1 January 1971.

10. Anon, PERFORMANCE OF AND DESIGN CRITERIA FOR DEPLOYABLE AERODYNAMIC DECELERATIONS, AM Power Jet Co., Ridgefield, N.J., and AFFDL, Wright-Patterson AFB, Ohio, ASD-TR-G1-579, December 1963.

experimental, has been accumulated with nongliding chute-recovered, ground impact Mini-RPVs.

The Navy/APL PRD-2, 80-pound gross weight delta wing Mini-RPV (Reference 11) has been chute recovered successfully in flight tests several times with a cross-chute and an air bag attenuation system. The flight pattern involved a zoom from level flight at a 50 foot altitude, to a peak altitude of about 150 feet where the chute was deployed.

The Belgian MBLE Epervier X-5 RPV, which is somewhat heavier than the present 200-pound max for the Mini-RPV class (324-pound gross weight) (Figure 11), has been routinely recovered by chutes with ground impact. Two foam-filled expendable ventral fins take the brunt of the landing impact.

The Navy/TRA Model 262 Mini-RPV has been chute recovered in flight tests from altitudes as low as 170 feet at chute deployment speeds of approximately 60 to 70 knots with only moderate impact damage. No provisions for resisting surface impact were designed into this particular RPV because it is intended for net recovery. The major portion of the impact loads were borne by a hemispherical simulated optical dome, the wing tips, and structure near the aft end of the RPV. In these instances the surface condition was hard-packed desert sand. (References 4, 5, 12, and 13.)

The XMQM-105 Aquila, also intended for net recovery, has been recovered successfully with a back-up chute system in flight test operations.

Thus, the surface impact mode of recovery for Mini-RPVs in particular has an aura of credibility, although based on a yet very modest amount of experience. The chute system for the Mini-RPV can generally be much simpler and the chute can

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11. Hill, M. L., LETTER, VAF-X-76-114, APPLIED PHYSICS LABORATORY, Johns Hopkins University, Laurel, Mo., to B. E. Kurz, 10 August 1976.

12. Kunzmann, R. V., ANALYSIS OF MODEL 262 MINI-RPV FLIGHTS PHASE I, TRA IDC to B. L. Dickens, TRA, San Diego, Ca., 20 August 1976.

13. Kunzmann, R. V., PRELIMINARY ANALYSIS OF MODEL 262 MINI RPV FLIGHTS, PHASE I, TRA IDC to B. L. Dickens TRA, San Diego, Ca., 22 August 1976.

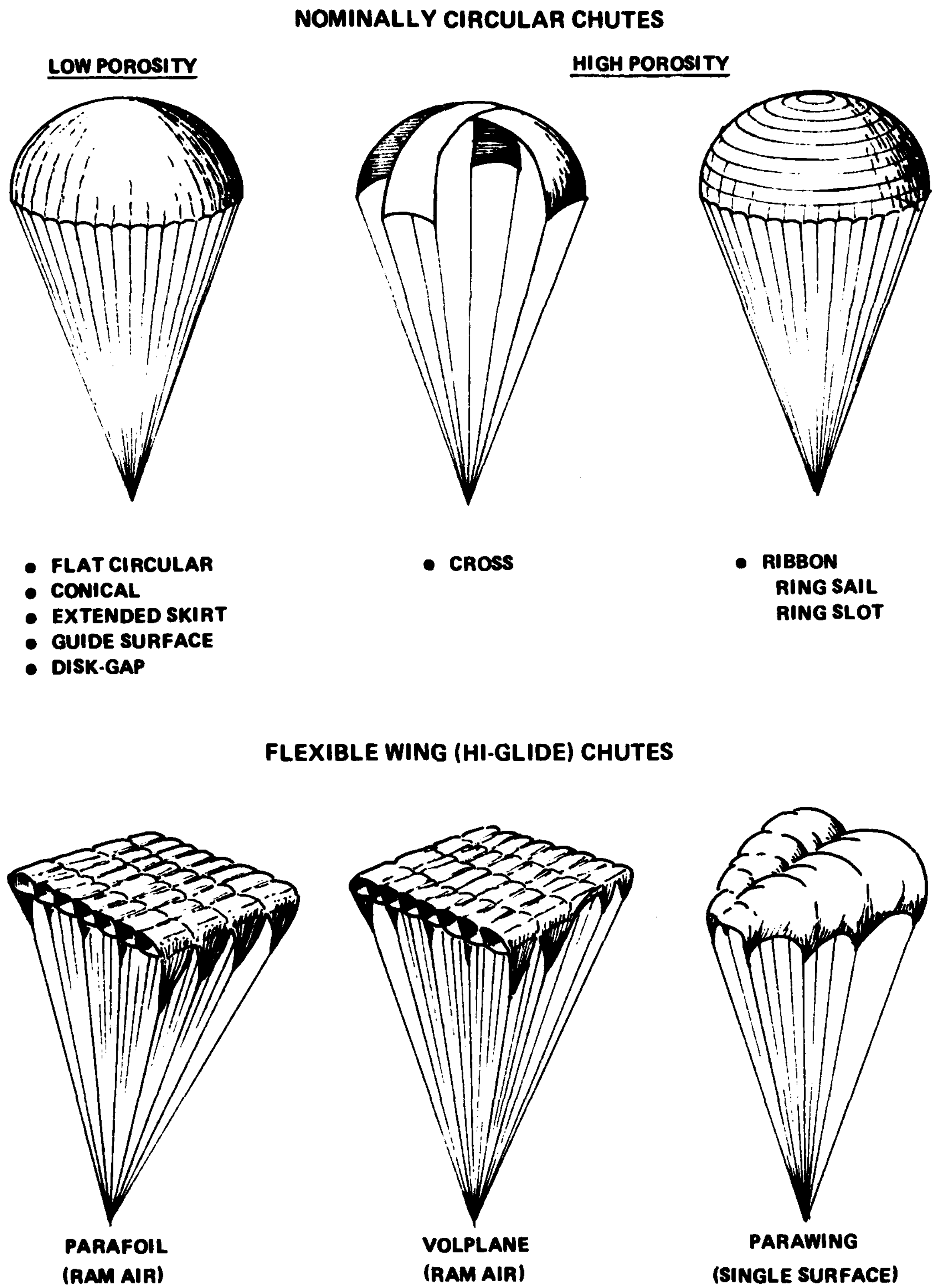

Figure 10. Representative Chute Configurations

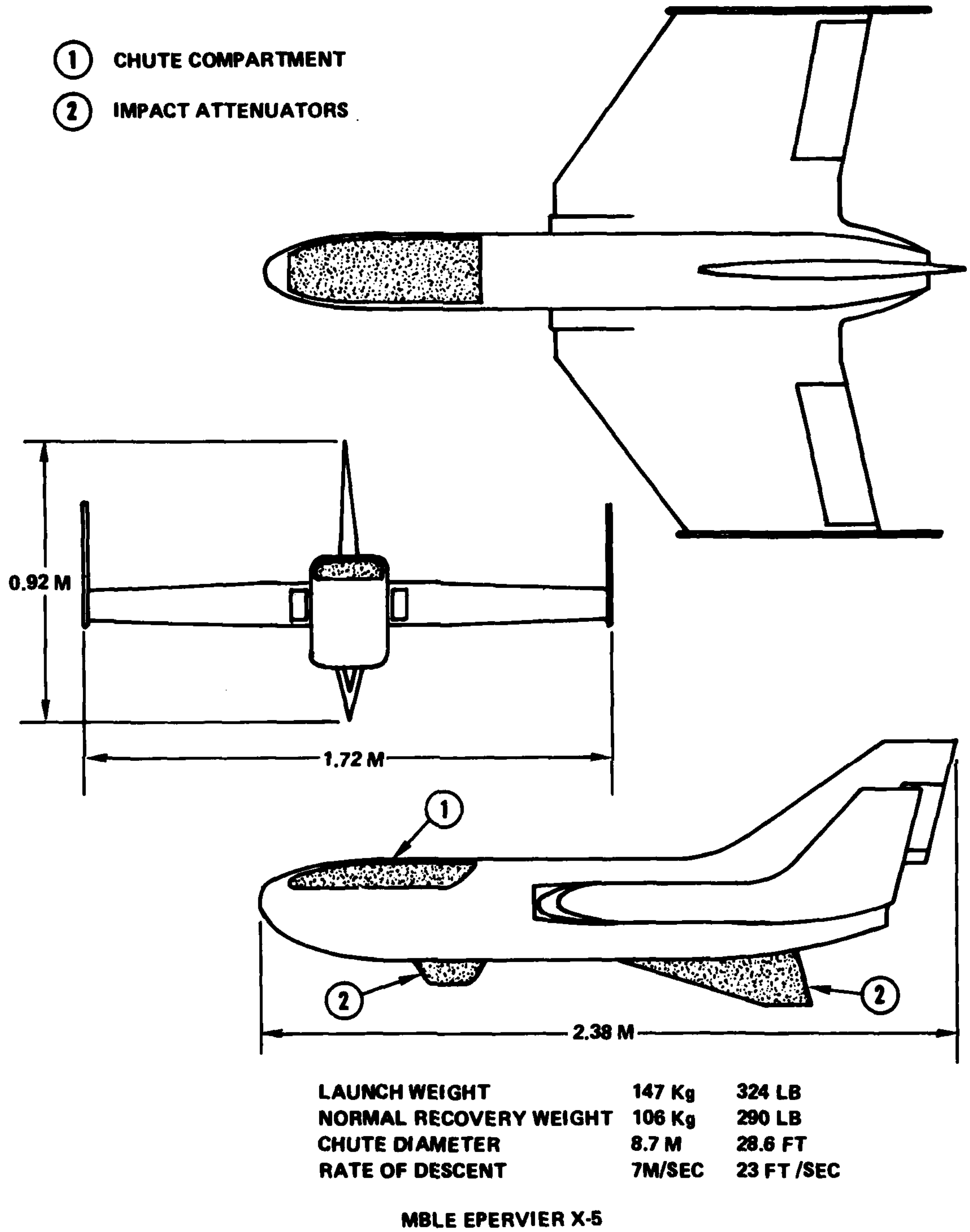

Figure 11. Typical RPV, Surface Impact Recovery

be deployed at much lower altitudes than for the larger, faster RPVs, thus diminishing the time to impact, the horizontal distance traveled, and the dispersion due to wind.

Gliding chutes (flexible fabric wing or hi-glide) are used as personnel chutes and have been employed experimentally for cargo delivery and manned powered flight. However, no substantial information is available at this time on prior experience with Mini-RPVs being recovered in the ground impact mode (see subsection 7.7, Concept II-4D for above-surface recovery with the hi-glide chute).

The following topics are discussed in this section.

7.2.2 Nongliding Chutes
7.2.3 Gliding Chutes, Concept I-2A
7.2.4 The Transferred Chute, Concept I-2B
7.2.5 Fabric Rotor, Concept I-2C

7.2.2 Nongliding Chutes, Concept I-2A

a. General. A review of pertinent sources of information, such as References 9, 10 and 14, provides no clear off-hand choice as to the optimum parachute configuration for the Mini-RPV surface impact recovery concept.

The typical nongliding Mini-RPV chute recovery system is seen as a simple installation including only a main chute, chute bag, and pilot chute, and with a deployment time of 1/2 second or less. No reefing provisions would be required.

As noted above it has been possible to improvise chute installations of reasonable weight and satisfactory performance for flight test purposes with off-the-shelf components. The Navy STAR TRA Model 262 Mini-RPV mentioned above employs a 30-foot personnel chute with a 0.5-second deployment time, at an installation weight of 15 pounds. The XMQM-105 Aquila has a 30-foot ribbon chute with a total installation weight of about 14 pounds, and the Navy/APL PRD-2 employs a 21-foot diameter

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14. ANON, CONCEPTS FOR RECOVERY OF MINI-RPV'S PER CONTRACT DAAJ02-76-C-0048 Pioneer Parachute Co., Inc., Manchester, Cn., Document Inq. 783, 11 August 1976

cross chute. Weight of the chute system and airbag impact attenuation system is reported to be 5.4 pounds.

b. Analysis

1. Trajectories

Flat-circular chute trajectories for the 120-pound and 200-pound class RPVs at their respective deployment speeds of 50 and 78 knots at 4000-foot, 95°F, are plotted in Figure 12. A deployment time interval of 0.5 seconds is included, and four different chute sizes are assumed for each class RPV.

The trajectories show that the greatest horizontal distance covered for a 200-foot deployment altitude is about 140 feet for the 200-pound RPV, with the smallest chute (24 foot diameter) investigated for that particular RPV. It is also seen that the chute could be deployed successfully at altitudes much lower than 200 feet. This fact was also noted in photographic coverage of the Navy STAR/TRA RPV recoveries, which showed that the stabilized descent mode occupied a large part of the total time interval from deployment to impact.

2. Target Window and Touchdown Options

The characteristics of the nongliding parachute recovery concept permit rather large target window dimensions and also considerable latitude in deploying the chute after the window is passed. For this particular case, the window is defined as an area at the entering edge of the recovery area extending between 50 and 150 feet in height (above the 15-meter high obstacle) and 400 feet in width.

In Figure 13 (a), a plan view of the 300-meter circular recovery area is shown with an assumed zone width of 400 feet in which the RPV could touch down. The earliest deployment is assumed to occur at 200 feet altitude at the edge of the recovery area (point A). The touchdown point would be 140 feet horizontally from point A. However the deployment command could be delayed until point B, about 670 feet farther down-field, and still effect a touchdown 100 feet inside the outer boundary of the recovery area. If the RPV is entering on a diameter of the area, the A-B delay can be extended to about 770 feet. Figure 13 (b) shows an elevation of the

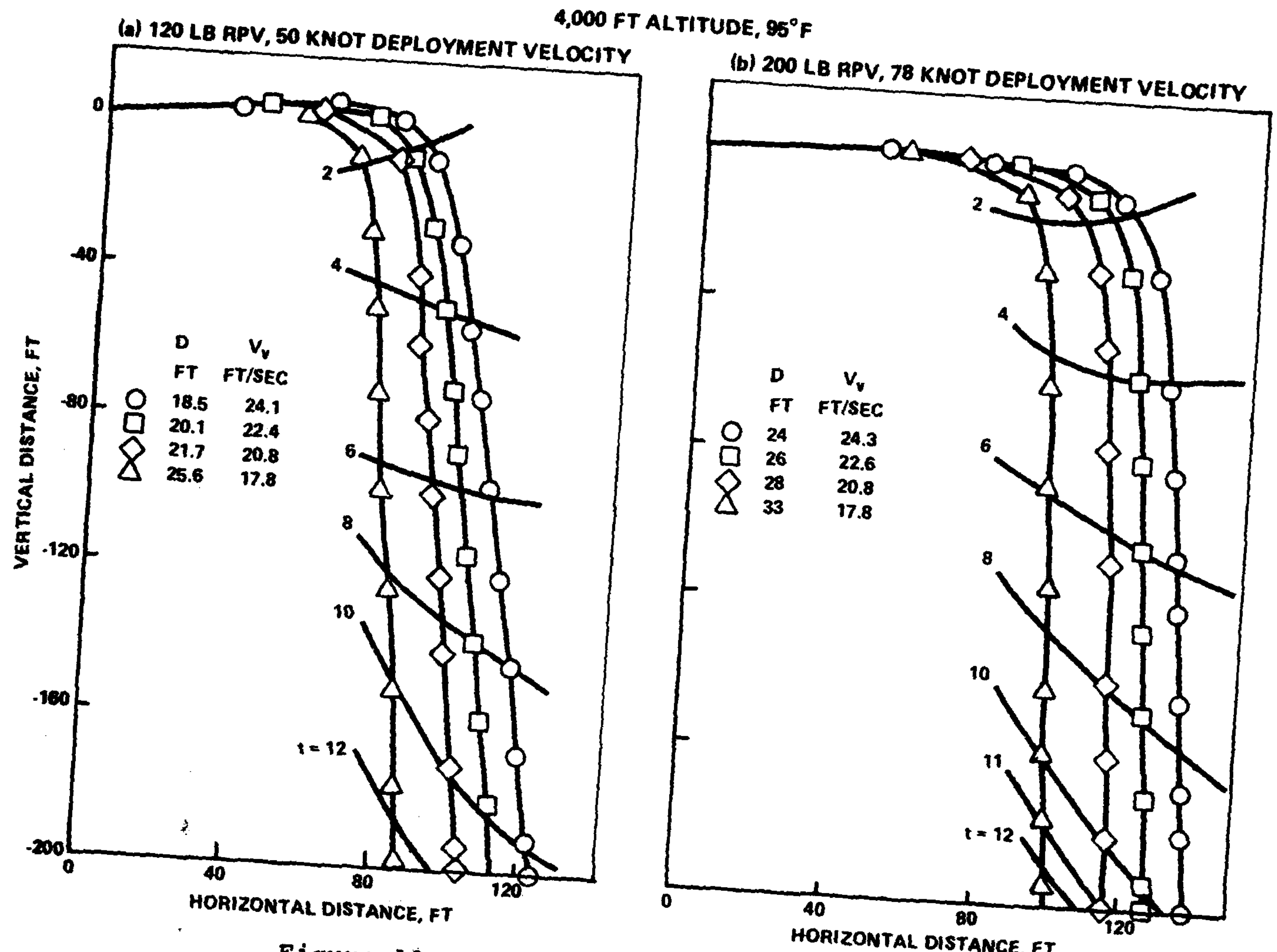

Figure 12. Flat Circular Chute Trajectories

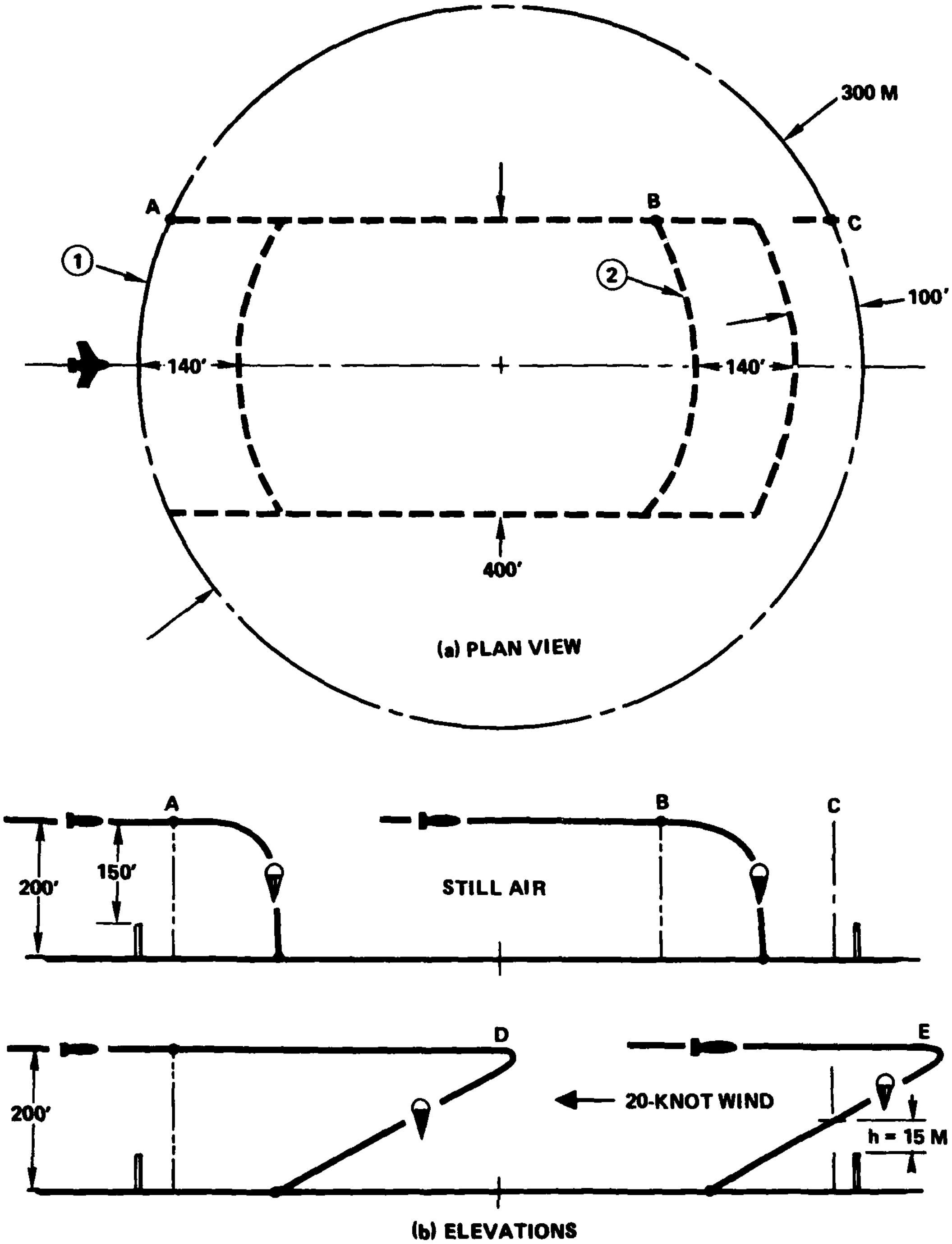

Figure 13. Recovery Zone Dimensions, Nongliding Chute

events occurring in the A to C plane.

The most severe condition for the surface impact parachute concept to contend with is perhaps the 20-knot wind criterion. Figure 13 (b) also presents an elevation view showing the effects of a 20-knot head wind. The setback distance from a 200-foot deployment altitude due to a 20-knot wind is estimated in terms of an average descent velocity of 21 feet/second based on a horizontal component of 20 x 1.69 = 33.8 feet/second.

The setback distance ratio is

$$33.8/21 = 1.61 \text{ ft/ft altitude}$$

or, for 300 ft alt, it is

$$200\ (1.61) = 322 \text{ ft}$$

Thus, if the chute is deployed at point D (slightly past the midpoint of the recovery area), the RPV would touch down at about the same point as when deployed at point A in still air. Or the deployment could be delayed until point E, approximately 590 feet later, where the trajectory would clear the 15-meter obstacle by a margin of 15 meters, and touch down about 160 feet inside the recovery area boundary.

By deploying the chute at lower altitudes, as is indicated to be possible by Figure 13, the setback distances due to wind can of course be proportionally reduced.

c. Concept Overview

The surface impact recovery system employing nominally circular, nongliding parachutes is a credible concept by virtue of its being operationally accepted over a period of years.

For application to Mini-RPVs, effort is needed to optimize chute weight and volume factors in terms of the low recovery weight and deployment speeds involved.

7.2.3 Gliding Chutes (Flexible Fabric Wing or Hi-Glide) Concept I-2B

a. General

The gliding, or flexible fabric wing (hi-glide) chutes, such as the parafoil, volplane, parawing or sailwing, offer the possibility of a smaller canopy area to give the same vertical rate of descent as a circular chute for a given Mini-RPV weight. A horizontal component, by definition, accompanies the vertical component for the hi-glide chutes in a ratio of between 2.5 and 3.0-to-1.0.

The hi-glide chutes apparently cannot be relied upon to follow a desired heading after deployment. This fact, and the existence of the appreciable horizontal velocity component, make some form of steering mandatory, unless a very large recovery area is consistently available and the possibility of landing downwind is acceptable.

Table 3 presents comparative data, mostly qualitative, on the general characteristics of the probable hi-glide chute candidates for Mini-RPV recovery. (Data obtained in follow-up discussions on Reference 14, 15, and 16.)

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15. Speelman, R. J. III, PARA-FOIL STEERABLE PARACHUTE, EXPLORATORY DEVELOPMENT FOR AIRDROP SYSTEM APPLICATION, AFFDL, Wright-Patterson AFB, Ohio, AFFDL-TR-71-37, April 1972.

16. Nicolaides, J. D. PARAFOIL POWERED FLIGHT, AFFDL, Wright-Patterson AFB, Ohio, AFFDL-TR-72-23, January 1972.

b. Analysis

Weights and Sizing

Weight information on gliding chutes for the purpose at hand, like the nongliding chutes, is scarce. Table 4 lists some available data for the parafoil, volplane, and parawing chutes of about the size of interest. The parafoil and volplane weights are for personnel-type chutes. The parawing weights are estimated from References 17, 18, and 19 and are undoubtedly on the light side. However, the weight trends appear to be in the expected order.

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17. Naeseth, R. L., LOW-SPEED WIND TUNNEL INVESTIGATION OF A SERIES OF TWIN KEEL ALL-FLEXIBLE PARAWINGS, NASA-Langley, Hampton, Va., Langley Working Paper, LWP-347, 9 January 1967.

18. Fournier, P. G.: Sleeman, W. C. Jr.: WIND TUNNEL STUDIES OF EFFECTS OF CONSTRUCTION METHODS, WING PLANFORM, AND CANOPY SLOTS ON THE AERODYNAMIC CHARACTERISTICS OF ALL-FLEXIBLE PARAWINGS, NASA-Langley, Hampton, Va., Langley Working Paper, LWP 349, NASA, 9 January 1967.

19. Gainer, T. G., WIND TUNNEL INVESTIGATION OF THE OPENING CHARACTERISTICS OF AN ALL-FLEXIBLE PARAWING, NASA-Langley, Hampton, Va., Langley Working Paper, LWP 344, NASA, 11 January 1967.

TABLE 3. COMPARATIVE DATA HI-GLIDE CHUTES

	FLEXIBLE FABRIC WINGS (HI-GLIDE CHUTES)		
	RAM AIR		SINGLE SURFACE
	PARAFOIL	VOLPLANE	PARAWING
$\frac{L}{D}$	2.75 to 3.0	2.75 to 3.0	2.75
Unit Weight, lb/ft^2	Approx 0.07	Less than Parafoil	>1/2 that of Parafoil
Deployment Time*	0.5 sec	0.5 sec	$\leq$ 0.5 sec
Stability	Stable	Stable	Slightly less Stable
Control	Controllable	Controllable, easier than Parafoil	Easier to control than Volplane

*Stowed to Inflated.

Considerable weight could be removed and packed volume could be reduced for both the parafoil and the volplane by designing such chutes for the specific requirements of the Mini-RPVs including low deployment speeds and the absence of precautions associated with man-carrying chutes.

In order to approximate how the gliding-type chute might compare to the nongliding chute, size and weight estimates based on a common parameter, i.e., vertical rate of descent, are made.

Figure 14 shows the relative planview dimensions of a parafoil gliding chute and a solid flat circular chute having the same vertical rate of descent, 20 feet/second, for a 200-pound RPV at 4000-foot altitude, 95°F.

Information for the parafoil is extracted from subsection 7.7 of this report.

The flat area of the circular chute is 616 feet, and the projected planform area of the parafoil is about 109 feet. Using an average unit weight of 0.015 pounds/foot for the circular chute and the average of the parafoils from Table 4, the estimated weights of the canopy and shroud lines are:

Solid Flat	616 (0.0133) = 8.2 lb
Parafoil	109 (0.071) = 7.7 lb

These basic chute weights represent 4 to 5 percent of the RPV gross weight. With a concerted effort to reduce these weights, it is entirely possible to provide a total chute installation weight of the order of 7 percent of the RPV's gross weight.

Additional data on the sizing of the parafoil type glides chutes for the 120- and 200-pound RPV is contained in subsection 7.7.

2. Concept Overview

The possibility of using the hi-glide chute for ground impact recovery has some attraction in that eventually it may be possible to provide a reasonably low canopy loading (lower chute size and weight), therefore lower vertical and horizontal velocity components for a slow, skid-in type landing. The realization of this prospect of course hinges largely on the development of lightweight, reliable, inexpensive airborne steering systems; and it is also dependent on further work to develop chutes specifically for Mini-RPV applications.

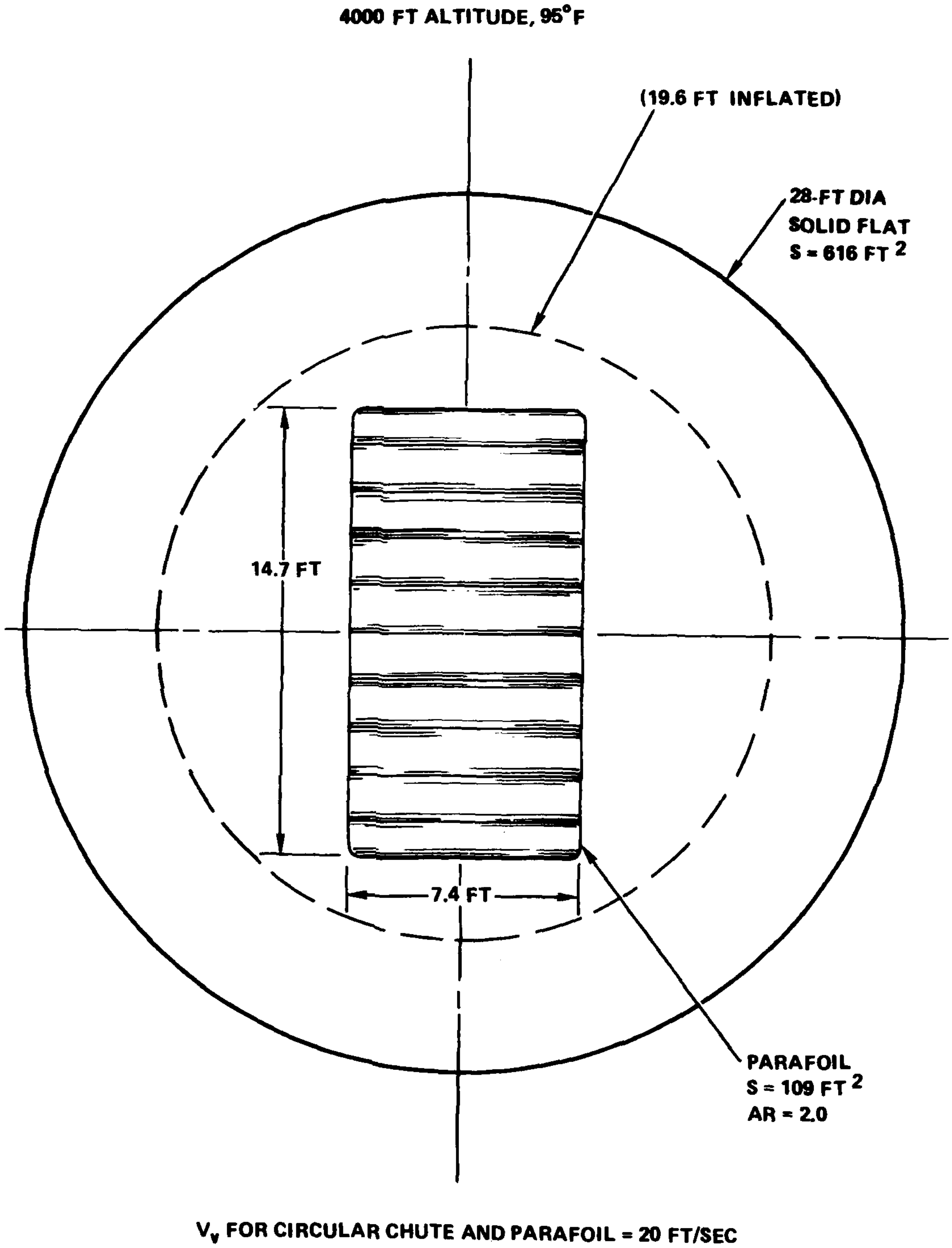

Figure 14. Chute Comparative Dimensions

A major overall problem in progressing with desired hi-glide chute development are the data voids presently found in the basic technologies involved. A recent study on this subject (Reference 20) concludes, in effect, that meaningful comparative analysis of the application of hi-glide canopies to RPVs is essentially prevented by numerous data voids.

c. Concept Conclusions

The paucity of available detail data does not necessarily obscure the potential of the hi-glide chute for surface-impact recovery for future application. However, it appears that the nongliding chute offers a less expensive and more satisfactory approach to surface impact recovery. Therefore the hi-glide chute will not be carried forward to Phase II for the specific purpose of surface impact recovery.

7.2.4 Transferred Chute, Concept I-2B

a. General

The transferred parachute recovery concept, illustrated in Figure 15 utilizes a recovery parachute unit transferred from the ground to the RPV (Reference 21).

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20. Gleason, L. L., A STUDY TO IDENTIFY DATA VOIDS IN THE APPLICATION OF HI-GLIDE CANOPIES TO REMOTELY PILOTED VEHICLES (RPV), AFFDL, Wright-Patterson AFB, Ohio, TECH REPORT AFFDL-TR-75-129, 30 June 1975.

21. ANON., PROPOSAL FOR THE SURVEY, STUDY, AND EVALUATION OF LAND-BASED, MINI-RPV RECOVERY SYSTEMS, TRA, San Diego, Ca., Report No. TRA 29308-46, 26 March 1976.

TABLE 4. WEIGHTS (HI-GLIDE) CHUTES

	AREA ft^2	WEIGHT lb	UNIT WEIGHT lb/ft^2
VOLPLANE			
Pioneer Hornet	200	8.75	0.0438
	118	6	0.0508
PARAFOIL			
Strato Star (AR - 1.15)	180	13	0.072
Strato Cloud (AR - 1.67)	230	16	0.069
PARAWING			
NASA LWP-344	17.29		0.021
NASA LWP-347	28.35		0.0176
NASA LWP-311	34.4		0.017

The system includes a rocket-propelled parachute similar to that employed in manned fighter aircraft zero-zero ejection seats. This unit, installed in its mortar, is placed on the ground at the recovery site. Auxiliary mortars containing rocket-propelled inert slug are placed on each side of the chute mortar. The slug of the two auxiliary mortars are connected to the recovery parachute unit by means of cables approximately 25 feet long.

The RPV to be recovered is equipped with a deployable pendant cable, on the end of which is a gang hook with catches to prevent release of cable caught by any of its hooks. This pendant cable is approximately 50 feet long. In operation the RPV, controlled by the terminal guidance system, is flown over the mortar emplacement. Lateral position, height, and speed of the RPV are controlled via the normal command and control link. The RPV is caused to fly over at a height of 200 to 300 feet; at the proper instant, the three mortars are automatically fired, boosting the parachute and slug upward as shown on Figure 15. These three projectiles, joined together by the cables, continue to travel upward. The RPV pendant cable will be contacted by one of the cables joining the three projectiles.

At about the point of contact the solid rocket motors of all projectiles will be expended. Momentum of the projectiles, however, will carry them upward, lifting the pendant cable. The forward motion of the RPV will cause the pendant cable to slide along the cable which contacted it until the hook engages that cable securely as shown in Figure 15. The parachute system deploys at approximately this time. This is a ballistic deployment/ opening, such as used on zero-zero ejection seat parachutes. The parachute inflates almost immediately and lowers the RPV to the ground.

b. Analysis

Intercept Velocity/Distance Relationships

The preferred design characteristics of the transferred chute system (to effect satisfactory intercepts with the Mini-RPV) would have to be determined by extensive studies, and undoubtedly experimental work.

The following simplified analysis of the intercept situation purports only sufficient understanding of some of the major problems to guide preliminary evaluations of the concept.

Figure 16 defines the basic intercept geometry. The intercept target point on the trailing pendant, A, at a distance from the vertical intercept plane is shown in Figure 16(a). Figure 16(b) indicates the interception of the projectile system, B, with the target point, A, on the pendant. The relationship between the RPV's velocity and that of the chute/projectile (C/P) system is derived below.

From

$$h = \left(\frac{V_v + V_o}{2}\right) t \tag{17}$$

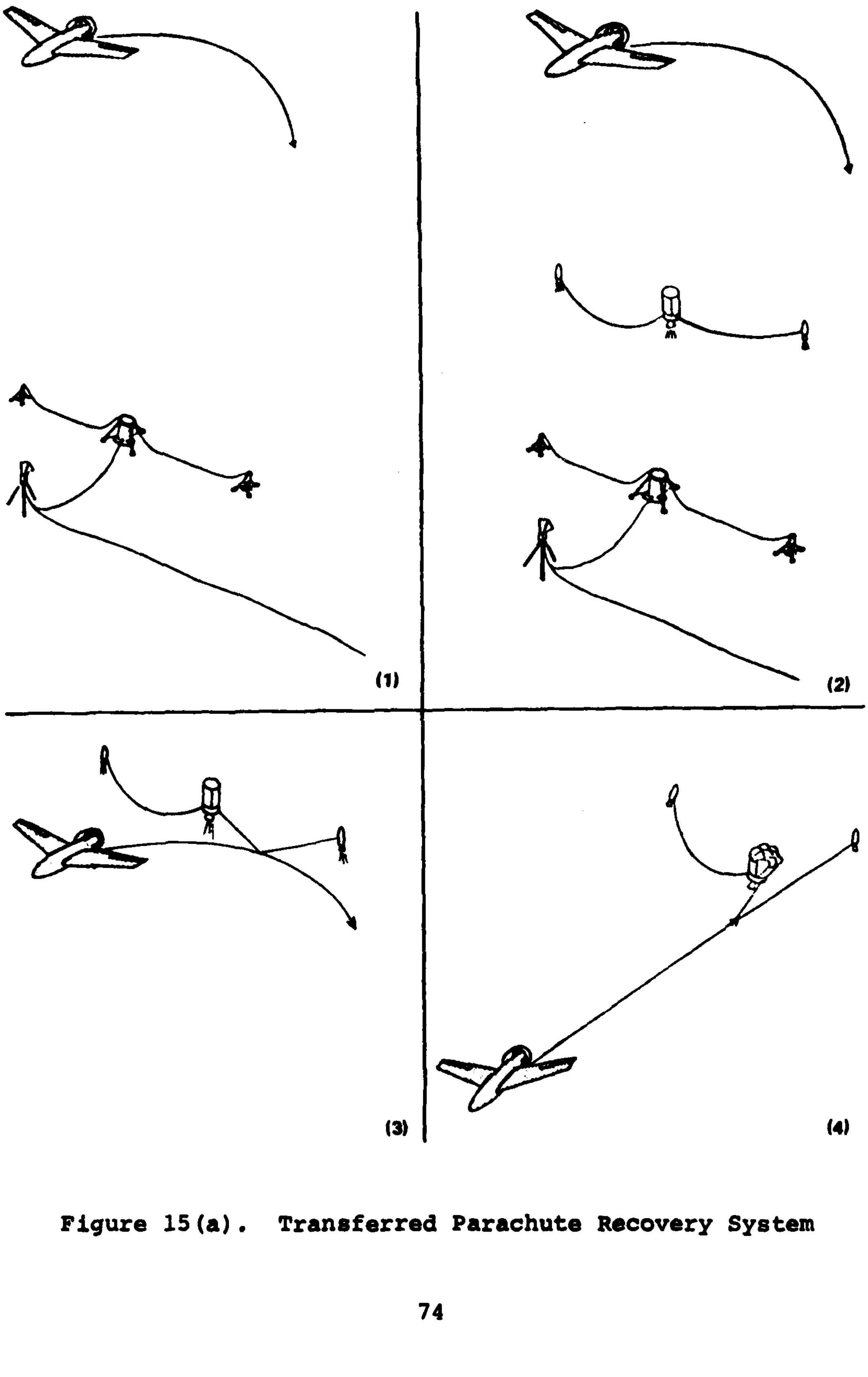


Figure 15(a). Transferred Parachute Recovery System

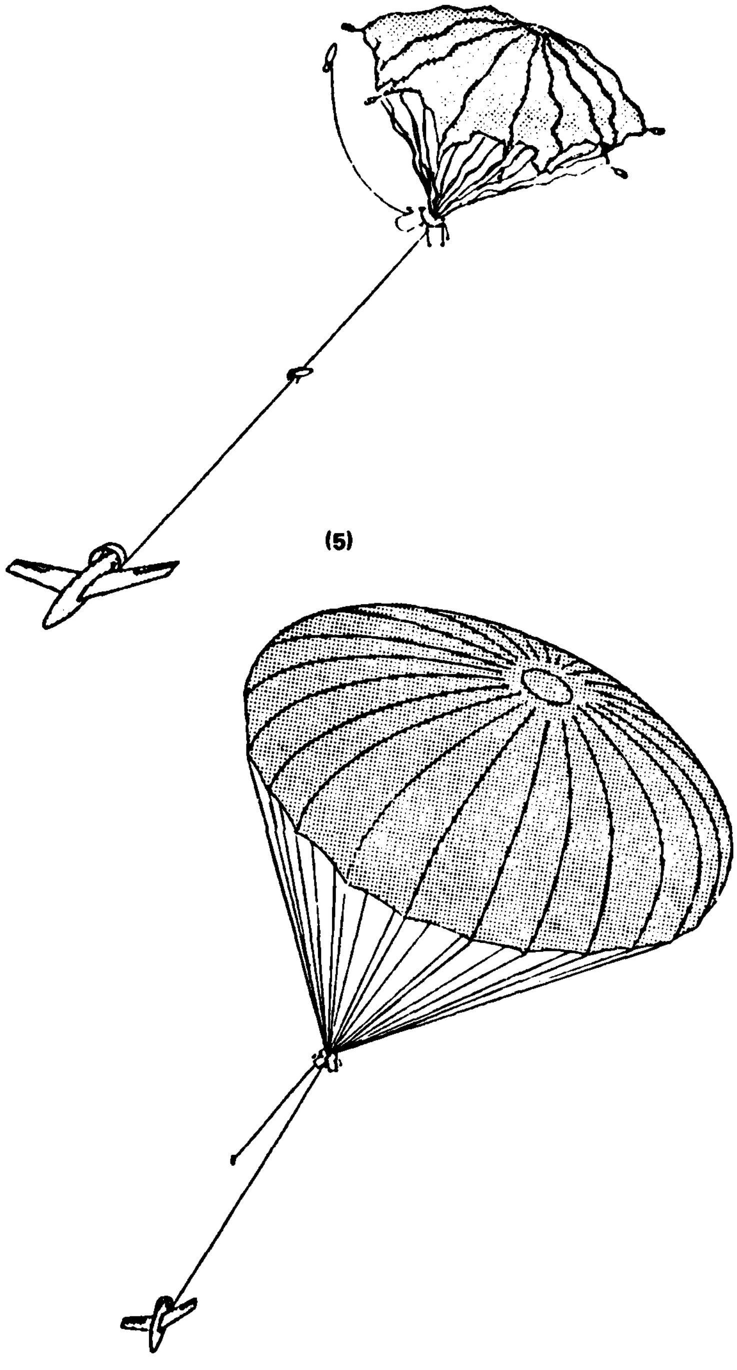


Figure 15(b). Transferred Parachute Recovery System (Continued) or, $V_v = \frac{2h}{t}$

where $V_O = 0$ and V_V = velocity of chute/projectile (C/P) system at intercept.

And

$$V = \frac{\ell i}{t} \tag{18}$$

Where V = velocity of RPV. By setting (17) = (18).

$$V_v = \frac{2hV}{\ell_i} \tag{19}$$

Thus, where $h = \ell_i$, the final velocity, V_v, of the C/P system is twice that of the RPV.

Figure 17 presents curves of time to intercept versus vertical velocity of the C/P system for altitudes of 200 and 300 feet above the surface.

Rocket Thrust

The rocket thrust, T, to produce the desired vertical velocity, V_v, at intercept can be determined approximately as

$$T = \frac{WV_v^2}{64.4n} + W \tag{20}$$

For this purpose, the C/P system weight will be assumed = 30 pounds. Equation (20) is used to compute the thrust values in Table 5.

C/P System and RPV Motion Characteristics

Three different intercept time intervals are selected as a basis for determining a spread of pertinent characteristics of the C/P system for comparison purposes. The first interval of 5 seconds is chosen to represent a relatively low vertical velocity; the second, 1.48 seconds, is an intermediate situation where $h = \ell_i$; and the third, 1.0 second, represents a fairly high V^i of 500 feet/second. The computation results are listed in Table 5.

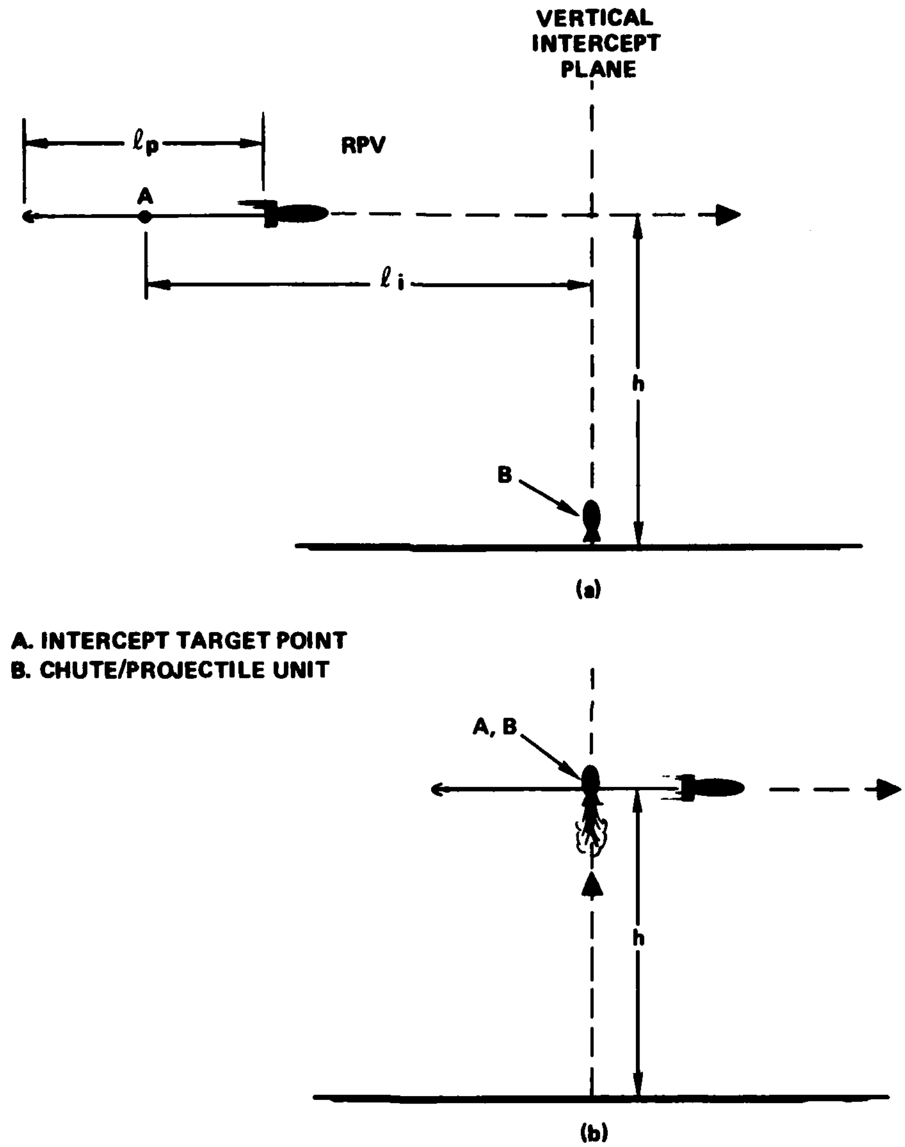


Figure 16. Intercept Geometry

For the purposes of this cursory investigation, only the chute projectile (C/P) unit is considered. The inert slug are assumed to follow suit. Further, the data of Table 5; (time, velocity, distance, rocket data, and energy) are based on an intercept altitude of 200 feet with the physical configuration similar to that depicted in Figure 15 (3). The rocket velocity is assumed to continue undiminished until a total of 75 feet (50 feet pendant plus 25 feet between the inert slug and the C/P unit) is reached.

It will be noted that the relationship of time to V_v in Figure 17 is rigorous. The estimated thrust required to produce a given velocity increases in error as V_v increases due to neglecting the aerodynamic drag of the C/P package. However, assuming a typical missile subsonic $C_{Do} = 0.3$, and a projectile diameter = 1.0 foot, the drag at the intercept value of V_v is only about 3 percent of the lowest thrust for V_v = 80 feet/second and about 9 percent of the thrust at the highest value of V_v = 500 feet/second.

The 200-pound class RPV at an approach speed of 78 knots is used as the basis for the characteristics analysis. Also, the intercept altitude is set at 200 feet above the surface to relate to previous chute studies. The equivalent atmospheric conditions are 4000 feet altitude, 95°F.

It will be noted that the rocket weight estimates in Table 5 for the different thrust levels are relatively low. It is most probable that a mass ratio of 0.6 would not be realized in solid propellant motors in such small sizes. However, the arbitrary, across-the-board total weight of 30 pounds allowed for the chute/projectile system is deemed adequate to cover the probable variations in rocket weight.

A significant result of the tabulated data is the energy levels estimated for the chute/projectile versus the RPV. For the longest intercept time of 5 seconds, the energy of the C/P is about 0.055 that of the RPV, while at the shortest intercept time of 0.8 seconds, the energy is in ratio of 2.16, or about 39 times greater.

Figure 18 presents diagrams which approximate the conditions, times, and distances from intercept to full extension of the 50-foot trailing pendant towed by the RPV plus the additional 25 feet of the cable between the inert slug and the C/P unit. The three different cases of Table 5 are represented.

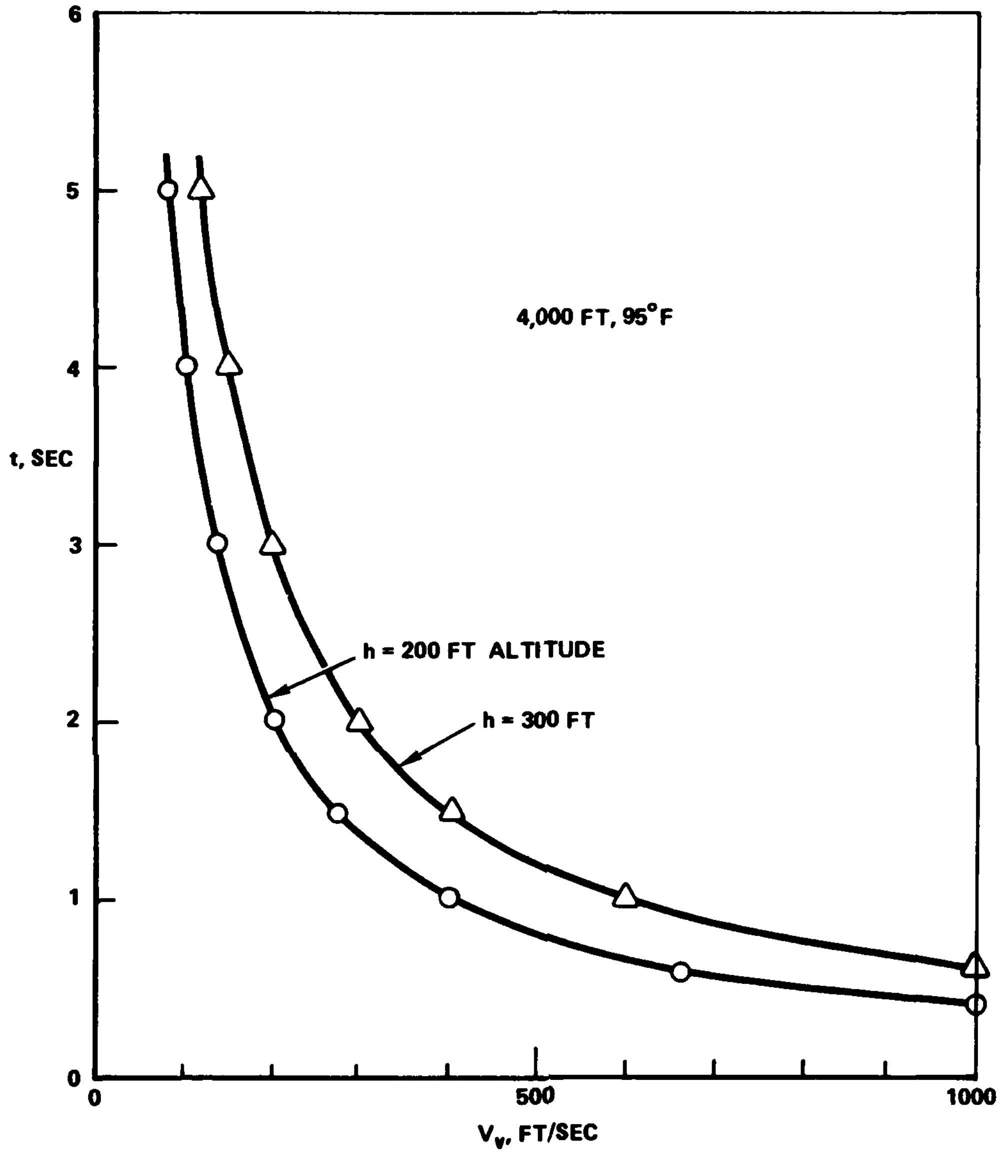


Figure 17. Vertical Velocity at Intercept versus Time

TABLE 5. CHUTE/PROJECTILE/RPV INTERCEPT CHARACTERISTICS

h = 200 FT ABOVE SURFACE — ATMOSPHERE = 4000 FT, 95° F

TIME, VELOCITY, DISTANCE			
	I	II	III
Time, t, sec	5	1.48	0.8
V_v, Final, ft/sec	180	270.3	500
V, ft/sec	131.82	138.82	131.82
l_i, ft	659	195	105
ROCKET DATA			
T, lb	45	200	612
I_{sp}, sec	210	210	210
$W_f = T/I_{sp}$, lb/sec	0.214	0.9524	2.33
$W_p = W_f$ (t), lb	1.07	1.40	2.33
$W_R = Wp/0.6$, lb	1.78	2.33	3.88
ENERGY			
RPV $= \frac{200\ V^2}{2g}$, ft lb	53964	53964	53964
C/P sys $= \frac{30\ V_v^2}{2g}$, ft lb	2981	34035	116459
RELATIVE E, (C/P)/RPV	0.055	0.631	2.16

The diagrams of column (1), Figure 18, are the same for all three cases, representing the instant of intercept of the projectile system with the midpoint of the pendant. An intermediate condition, column (2), shows the geometry of the system after the pendant cable has slid for 10 feet across the ascending line being carried by the projectiles. The final case, column (3), represents the instant of full extension of the lines.

The total distance traveled and the total time interval for each case is noted in column (3). The rubbing (or friction velocity) of the pendant sliding across the perpendicular line for an arbitrary pay-out distance of 25 ft. (intercept point to grappling hook) is estimated as:

Case	I	II	III
Velocity (ft/sec)	76	167	258

The approximations of Figure 18 provide semiquantitative indications of the order of dynamic problems to be encountered with the transferred chute concept. Further analysis would probably sort out a maximum allowable vertical velocity for the chute/projectile system that maintains a reasonable balance among the factors involved. One important trade-off will be that of the magnitude of the projectiles' vertical velocity versus the intercept distance, ℓ_i; that is, the lower the vertical velocity, the greater the distance becomes, thus allowing more time for perturbations to occur.

<u>Extended Suspension Line</u>

The length of the single suspension line, between the RPV and the chute, nominally 75 feet, should pose no particular problem in so far as sufficient deployment altitude is concerned, since the chute would be deployed above 200 feet altitude while traveling upward (Figure 19).

However, the pendular action possible with such a long line is of concern. As noted in Figure 18, the problem would be more pronounced where the vertical velocity of the C/P unit is relatively low with respect to the RPV's velocity, causing a greater initial swing-back angle θ. Random occurrences would find the RPV impacting the earth with appreciable horizontal velocity due to the pendular action of the unusually long suspension line.

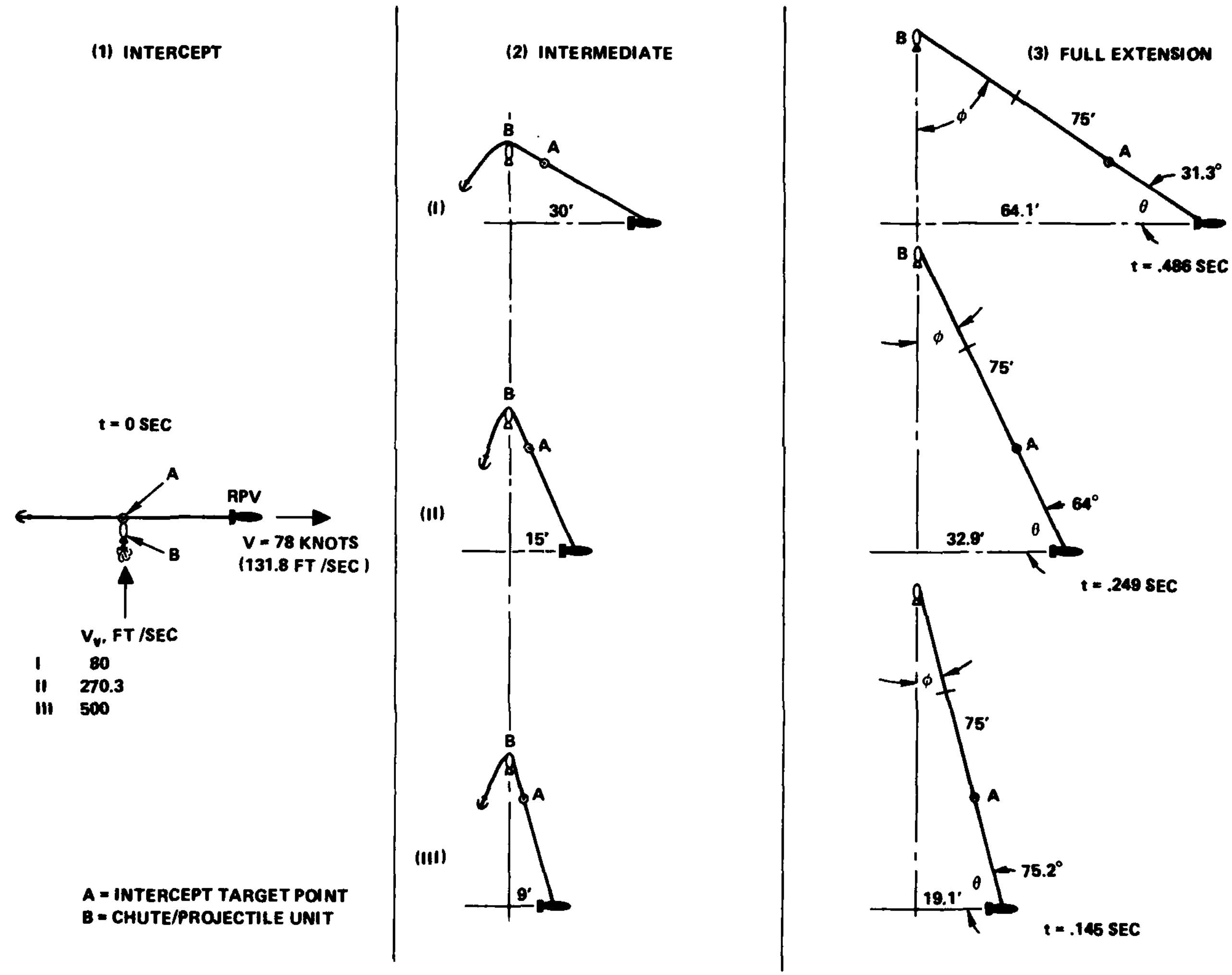


Figure 18. Intercept Time and Distance

Wind Effects

The actual amount of drift due to a 20-knot head wind is dependent on the wind gradient which occurs near the surface of the earth, air turbulence, and the linearly varying velocity, V_v, of the C/P system, and that of the RPV.

A rough idea of the amount of drift or offset that might occur for the three cases of Table 5 is obtained by assuming the average vertical velocity, V_v, to apply throughout the height, h, in combination with the 20-knot wind. The same results are obtained by assuming that the drift distance is equal to the wind velocity (33.8 ft/sec x t). The distances are:

	Case	I	II	III
V		80	270.3	500
ℓ	(ft)	169	50	27

thus the intercept distance, ℓ_i, from the vertical intercept plane would become shorter in the downwind direction by the drift distances shown.

Target Window

The window height, or the allowable vertical distance error for the RPV at the vertical intercept plane, is basically a timing consideration. For example, an error of $\pm$ 5 feet would relate to a horizontal error for striking the desired intercept point on the pendant of $\pm$ 8.3 feet for the C/P unit traveling vertically at 80 feet/second, but only $\pm$ 1.3 feet for the case of traveling vertically at 500 feet/second. Otherwise the error of $\pm$5 feet would probably have little physical consequence.

The allowable lateral error would depend on how far outboard of the chute/projectile package the lateral lines could strike the RPV's trailing pendant (Figure 15) and still effect a satisfactory hook-up. This is estimated at approximately $\pm$ 20 feet.

An additional factor to be reckoned with is the speed control of the RPV to assure the proper time of arrival at the vertical intercept plane. The total error depends on any lag in the detection, computation, and command cycle time of the terminal guidance system and

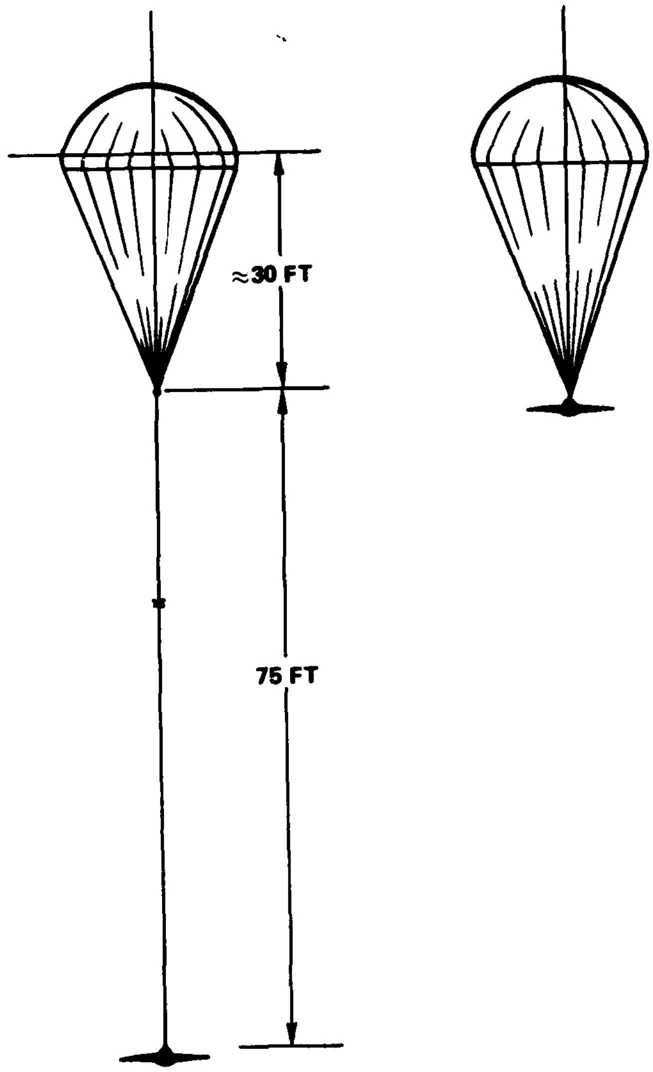


Figure 19. Extended Suspension Line

the response time for the RPV's drag/propulsion combination.

c. <u>Conclusions</u>

The major benefits of the transferred concept are: (1) a relatively low airborne weight and volume for the trailing pendant cable installation, and (2) lightweight, portable ground equipment with a small visual signature. The ground equipment could be adjusted for wind shifts within the allotted 5-minute interval.

The transferred chute concept would require in-depth analytical studies and perhaps simulation analysis to accomplish the numerous parameter trade-off situations that would be required for a satisfactory technical definition of the system.

A preliminary indication of the types of deviations, and consequently, implied error sources, is obtained from the cursory analysis and discussions above. Unique among the significant error sources is RPV speed control, which is less critical for the other recovery concepts of this study. Another typical error source is the rocket system which depends on precise, coordinated performance of three solid propellant rocket motors traveling in free flight. Individual differences in rocket motor performance due to normal manufacturing tolerances would affect coordination within the system. Ambient, conditioned temperature differences would affect the overall thrust output of the system.

In addition to the operational problems created by error sources, mechanical problems resulting from the dynamics of the intercept, engagement, and chute deployment functions are to be considered. These include friction effects of the lines crossing at moderate to high relative velocities, snatch loads due the RPV and C/P units traveling at right angles to each other, the mass of the one free inert slug swinging into and damaging the chute shroud lines, and possible damage to the RPV at touchdown caused by pendular motion caused by the extended suspension line.

In summary, the technical risk and probable development cost and time that would be incurred in perfecting the transferred chute concept appear, at this time, to subordinate the concept's benefits.

7.2.5 Fabric Rotor, Concept I-2C

a. General

The fabric rotor shown in Figure 20 is in effect a form of auto-gyro that would serve essentially the same purpose as the hi-glide parachutes for mini-RPV recovery. The fabric rotor concept discussed below is an adaptation of a proposed cargo delivery system described in References 1 and 6. Results of deployment tests on a 40-inch diameter model of the fabric rotor are also discussed in Reference 1.

As depicted in Figure 20 (1), the packaged fabric rotor assembly is deployed in a bag extracted by a small chute. The bag/chute unit is ejected. The rotor mast, A, the rotor control arms, B, and the rotor head arms, C, unfold in an umbrella fashion with the tip of the fabric rotor, D, restrained (reefed) at the ends of the control arms, B.

In the second stage (2) the reefed rotor/RPV unit is descending vertically to begin the primary spin-up mode. Initial rotation of the inflated chute is started by the turbine effect of air passing through ventilation slots, F, at the base of each fabric rotor blade. The slots are created by attaching the fabric of the root of each rotor blade to only one side of each rotor head arm. The rotational speed in the primary mode is about 350 RPM.

Rotational speed automatically increases in the secondary spin-up mode (3) as a portion of the rotor blade tips extend caused by the centrifugal action of small tip weights, G. In this configuration the rotor diameter is fixed by small hold-down cables until the rotational speed increase, caused by the windmilling action of the horizontally extended portions of the blades, reaches about 900 RPM. The rate of descent will decrease somewhat in this stage due to the increased effective drag area. The hold-down cables again release as 900 RPM is attained, and the blades extend fully in the final stage, (4), to go into the autorotational mode, where the rotor speed would decrease to the order of 230 to 260 RPM.

The rotor mast control arms, B, function as a swash plate actuated by a small servo system, H, attached to the rotor mast. Lightweight cables, J, transmit swash plate forces to the rotor head arms.

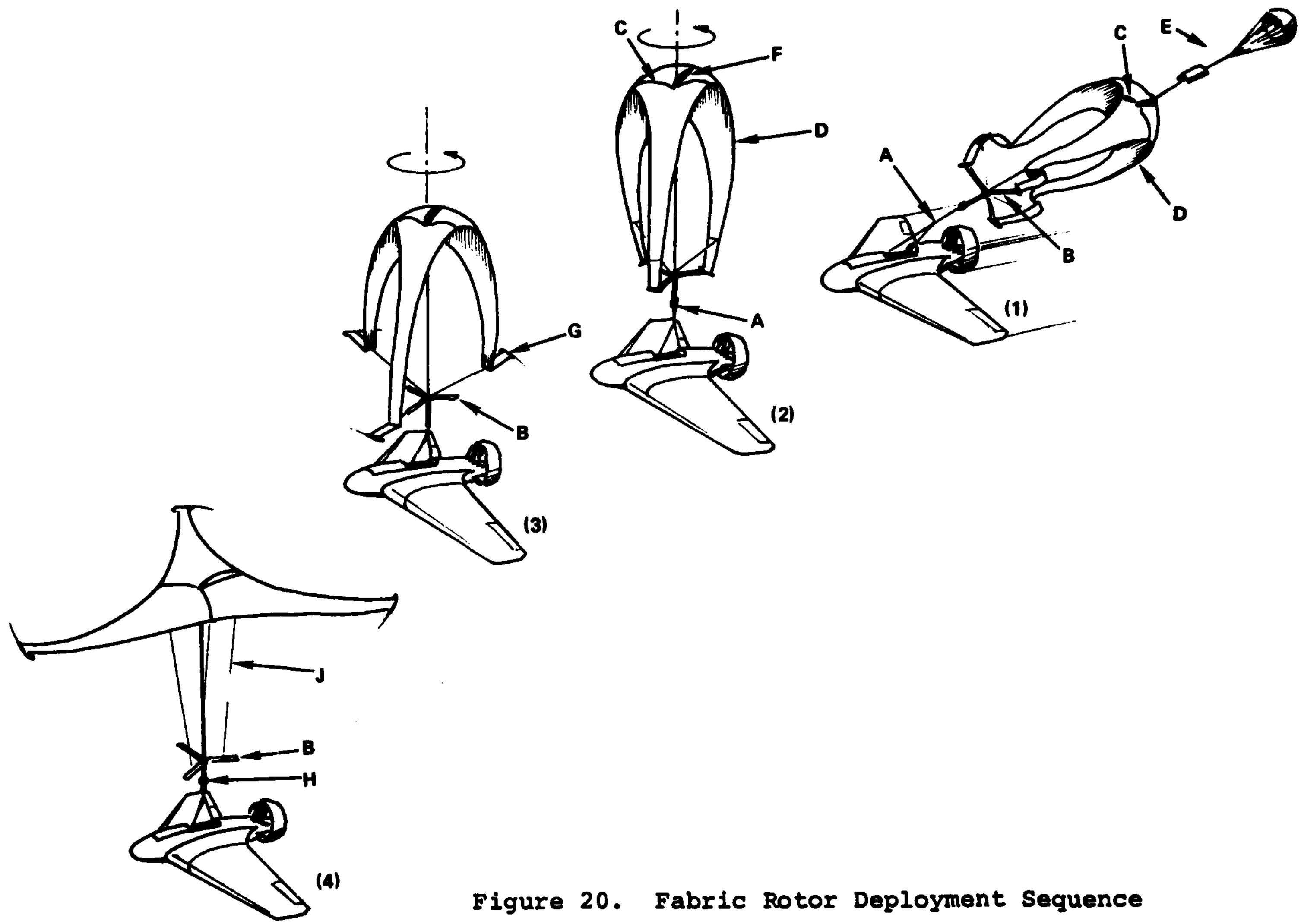


Figure 20. Fabric Rotor Deployment Sequence

The fabric-rotor/RPV unit may then be steered toward a predetermined landing area. A gentle landing at a forward speed of the order of 10 knots, and a sink speed of approximately 2 feet/second is accomplished by executing a flare in close proximity to the ground. This flare can be initiated by means of a pendant ground contact switch trailing on a short length of line.

b. **Analysis**

Rotor Performance

A brief analysis of the fabric rotor (gyrosail) performance is summarized in the curves of Figure 21. Assumptions used in the analysis include:

Rotor Solidity, σ	= 0.20
Rotor Diameter, ft	= 14
Angle θ_{tip}, deg	= 5
Angle θ_{root}, deg	= 0
Recovered Weight, lb	= 220

The profile drag coefficient of the fabric rotor is assumed to be three times that of a standard airfoil, and the equivalent drag area of all else except the rotor is 1.84 feet. Rotor tip speeds for the cruise flight range of data (less than 20 feet/second) are estimated to vary from about 170 feet/second to 190 feet/second, increasing with forward speed. The curves shown are based on sea level standard conditions. At the 4000-foot altitude, 95°F condition, the L/D versus airspeed curves would shift to the right along the airspeed axis by about 10 percent, and the sinking speed would increase a like amount.

As will also be seen in Figure 21, the rotor pitch control system included in the fabric rotor concept, would permit a choice of L/D ratios from about 1.5 to about 3.7, with small changes in sinking speed (16.5 feet/second to 20 feet/second). This feature provides a variety of flight path options of from about 15 degrees to 34 degrees.

Weights

The weight of the rotor installation, including the

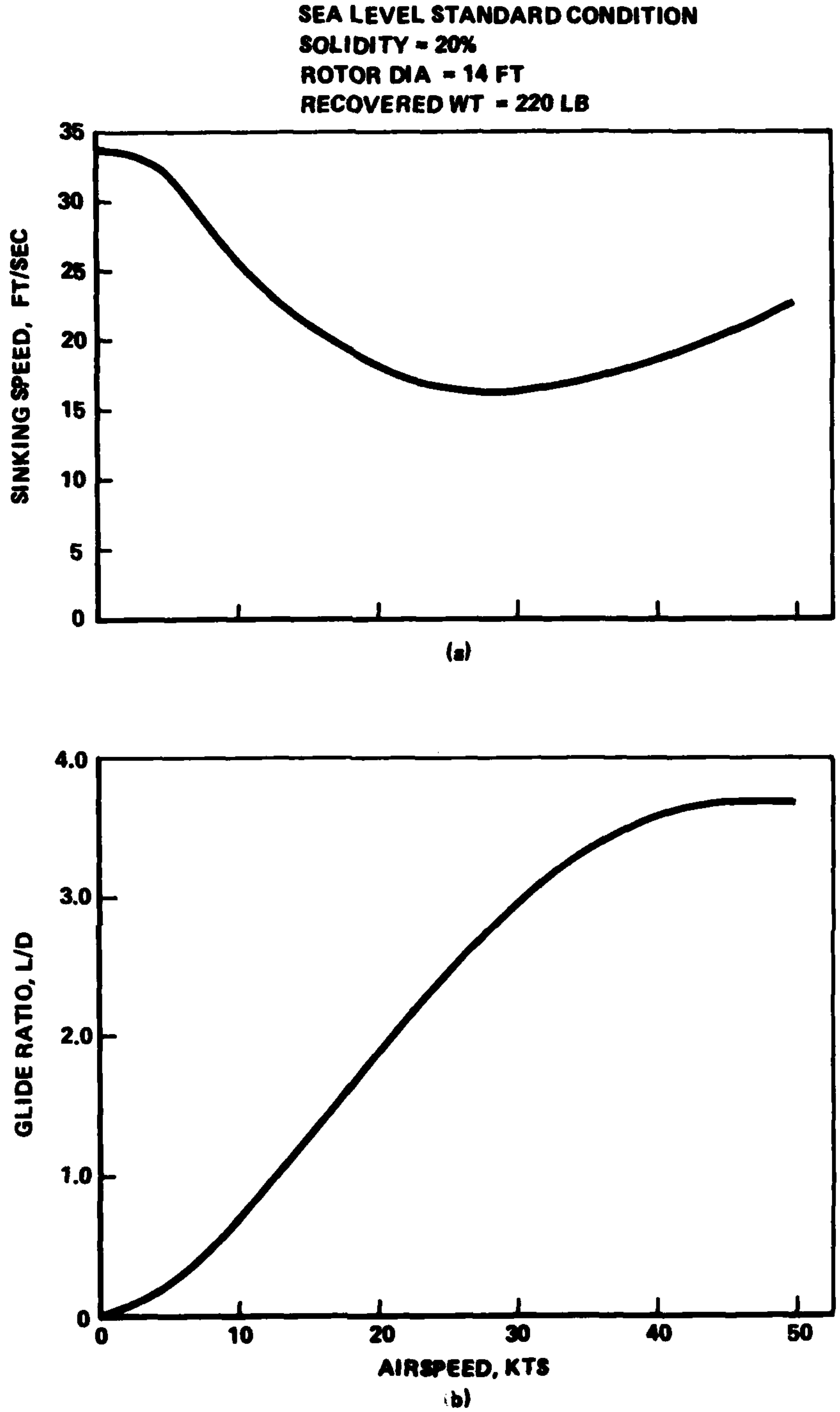


Figure 21. Fabric Rotor Performance

rotor blade tip-weights (about 3 pounds each), but inclusive of the airborne avionics chargeable to the rotor system is estimated at 25 pounds by scaling down the rotor system in Reference 1.

Comparison to Parafoil

Purely coincidental, but interesting to note, is how the performance of the fabric rotor compares in size to a parafoil of nearly the same performance. Using minimum sink speed for the fabric rotor as the criterion, it is seen in Figure 21 that the L/D ratio is 2.75 and the velocity is 27.5 Knots.

Comparative data are presented below. The parafoil parameters are taken from subsection 7.7.5 of this report.

	V, ft/sec	L/D	V, knots	W/S
Fabric Rotor	16.5	2.75	27.5	1.43*
Parafoil	15.0	2.75	25.98	1.04

*Disc Loading

c. Conclusions

The principal advantage of the fabric rotor concept from the standpoint of intended U.S. Army field operations is similar to the nongliding or gliding chute concepts in that the required ground support equipment is minimal.

A disadvantage of the fabric rotor concept is the required deployment altitude of approximately 1000 feet implying a longer exposure to visual, and perhaps other means of detection than that of the nongliding, or hi-glide chutes.

In common with the hi-glide chutes (subsection 7.2.3) the fabric rotor requires an airborne steering system.

Both the fabric rotor and the hi-glide chutes can be flared to soften the landing impact by adding the required functions to either control system.

The airborne equipment for the fabric rotor system would be heavier, more expensive, and less reliable in terms of its increased complexity than that required for the hi-glide chute.

At touchdown, the rotational energy stored in the rotor constitutes a hazard to the rotor system, the RPV, and to personnel safety when the tip weights strike the ground.

For the purpose of Mini-RPV surface impact recovery, the fabric rotor appears to offer no overall advantage over a hi-glide chute system.

7.3 Vectored Retro Rocket, Concept I-3

7.3.1 General. The use of Retro Rockets to decelerate airborne objects to very low or zero velocities at touchdown is an established technology in space applications. Retro Rockets have also been used in a few cases for air vehicles (Red Headed Road Runner, for example) in conjunction with the parachute.

The Retro Rocket concept set forth here (Figure 22) is based on: (1) firing an airborne rocket motor line with the flight path at very low altitudes to bring the Mini RPV to rest on the ground in relatively short distances, or (2) firing two or more rockets to provide the appropriate retarding force vector.

For the purpose of this study, only proposition (1) above will be examined.

The relatively low altitudes involved for the initiation of the rocket thrust suggests that a terrain-sensing stinger could be deployed by spring action during or before the landing approach segment. The alternative to a simple device of this nature would probably be more elaborate and complex electronic sensors such as a low altitude radar altimeter and circuitry to command rocket firing. Extendable skids with limited shock attenuation capability could be used to provide support for the RPV on the ground.

7.3.2 Analysis. It is apparent that the critical factors in the overall performance of the Retro Rocket system are firing at the proper height, h_1, and having the RPV's altitude reasonably close to that desired.

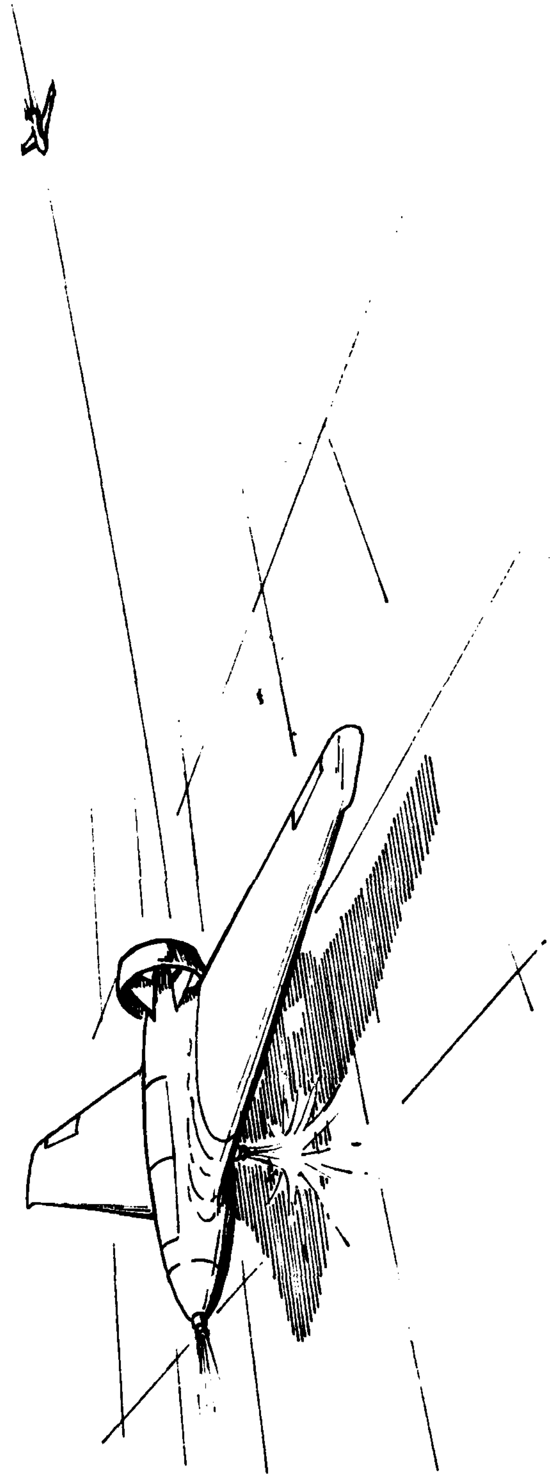


Figure 22. Retro Rocket RPV

In space applications, deceleration by retro rockets, pitch, roll, and yaw trim are usually achieved by small auxiliary thrusters, which, in turn, require attitude sensors and thrust modulation equipment.

For the Mini-RPV, keeping subsystem complexity to a minimum should be a relentless goal. Therefore, success in keeping the Mini-RPV Retro Rocket system simple may rest on: (1) selecting parameters to keep the height, h_1, very low, and (2) very accurate alignment of the rocket thrust vector with the CG of the RPV. Keeping the height low is in the nature of "getting-it-over-with" before very much can go wrong. On the other hand, the lower height implies higher rocket thrust to decelerate.

Distances and times to decelerate the 120- and 200-pound class RPVs are tabulated in Table 6. These numbers are based on an approach path of 6 degrees and on the assumption that the retarding force of the rocket is constant throughout.

The flight path distance to decelerate to zero velocity and the time interval involved are computed by:

$$\ell_r = V^2/2gn \qquad (21)$$

and

$$t = V/gn \qquad (22)$$

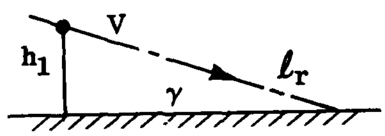
Where V = velocity at rocket ignition,
η = deceleration load factor in g.

Window

The approach window and flight path corridor for the Retro Rocket RPV would be much the same as that for the typical patterns discussed in Section 4.0. The actual length of the approach leg, ℓ_a, would be greater than for most of the other recovery concepts since the Retro Rocket RPV continues directly to the surface of the ground; that is where $h_1 = 0$. Thus, if the RPV passes through the center of the typical approach window (22.5 meters, 73.8 feet above the ground) on a 6-degree flight path, the touchdown point would be 73.8/tan 6 degrees = 702 feet beyond the approach edge of

TABLE 6. RECOVERY DISTANCE AND TIME COMPUTATIONS

G.W. = 200 lb, V = 78 knots (131.82 ft/sec), $\gamma = 6°$							
①	②	③	④	⑤	⑥	⑦	
η g s	ΔV ft/sec	ΔV^2	$2g\eta = 2g$ ①	$\ell r =$ ③ / ④ ft	$h_1 = \sin 6° \times$ ⑤	$t_1 = \frac{②}{①\,g}$ sec	
3	131.82	17376.5	193.2	89.94	9.40	1.36	
6	131.82	17376.5	386.4	44.97	4.70	0.682	(a)
12	131.82	17376.5	772.8	22.49	2.35	0.341	
G.W. = 120 lb, V = 50 knots (84.5 ft/sec), $\gamma = 6°$							
3	84.5	7140.25	193.2	36.96	3.86	0.875	
6	84.5	7140.25	386.4	18.48	1.93	0.437	(b)
12	84.5	7140.25	772.8	9.23	0.96	0.219	



Vectored Retro Rocket Concept I-3

the recovery area. However, since the height, h_1, at which the rocket is fired and the pitch/roll attitude of the RPV are the major concerns for landing, the approach distance is not critical if the terrain is acceptable for touchdown over a large area. Likewise, the lateral position of the RPV with respect to the surface would not be critical. In effect, the target window consists mostly of the dimension, h_1, at which the rocket is fired.

7.3.3 Conclusions The brief investigations for the Retro Rocket concept conducted above provide only preliminary background for discussing the concept.

The Retro Rocket concept is basically attractive in that it is a totally airborne system requiring minimal recovery ground equipment.

Hazards involved are those associated with pyrotechnics in general, and the possibility of fire when recovering on dry grass or weeds. The effects of rocket blast on the outer surfaces of the RPV, payload dome, and skids (if used) must be taken into account.

The signature (visual, radar, etc.) created by the Recovery Operation would be only that of the RPV itself approaching the landing area until the rocket is fired. With smokeless propellants, with a short burn time, and being very close to the ground, the rocket visual signature should be negligible. However, the possibility of a lingering dust cloud thrown into the air by the rocket's blast could, on occasion, provide an appreciable signature. It's acoustic signature may not be significant due to the rocket's short burn time.

7.4 Stowed Rotor Concept I-4A

7.4.1 General The Stowed Rotor, or Autogyro Recovery System concept described below is adapted to the basic Aquila XMQM-105-type Mini-RPV as shown in Figure 23. This concept was obtained as a result of the data survey (Section 6.0 of this report).

The concept is described here in direct quotation from the data survey submittal (Reference 22):

"This paper describes an airborne recovery system which uses the principle of auto rotation. Basically, this system would use from two to four folding rotor blades. The blades would fold alongside the fuselage during normal mission operations of the RPV; thus, resulting in a "least drag" configuration. Each blade would be hinged to a central hub at the aft end of the fuselage. During normal mission operation of the RPV, the blades would be locked alongside the fuselage by a simple locking mechanism. When it comes time to retrieve the RPV, the RPV would be directed to fly over the ground station at some minimum altitude and on as flat of a power-off glide as possible. The ground station would then command the RPV to release the locked rotor blades. The spring-loaded blades would then open into a common plane which is perpendicular to the glide path of the RPV; thus, resulting in a configuration of "maximum drag". The forward motion of the RPV would be slowed by the drag from the rotor blades. This drag would also cause the blades to rotate, which also increases the drag on the RPV. After losing air-speed the wing of the RPV would stall and the RPV glide path would change from a horizontal direction to a vertical direction. The rotation of the blades would create enough lift to slowly lower the RPV to a safe vertical recovery."

7.4.2 Analysis

a. Performance - The principle of descending vertically in the autorotative mode is an established segment of rotary wing technology. Curves of estimated rates of descent for the 120- and the 200-pound class RPVs in terms of rotor diameter, with a drag coefficient of 1.2

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22. Borrer, J. L., AUTOGIRO RECOVERY SYSTEM FOR MINI RPV (BRIEF PAPER), Dickinson, Tex., 12 October 1976.

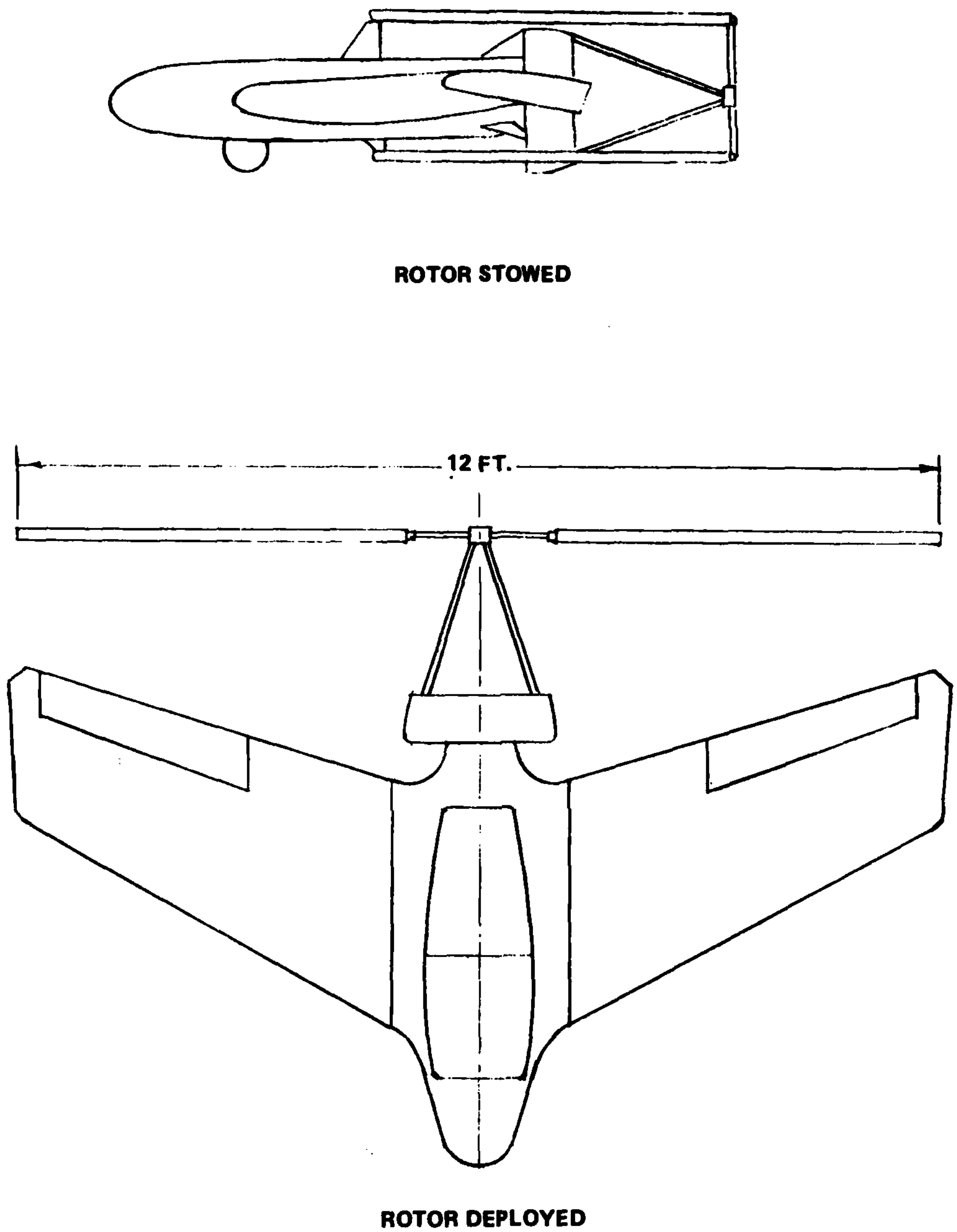

Figure 23. Stowed Rotor RPV

(Reference 23), which hopefully is representative of the vertical descent mode of rotor operation for the Mini-RPVs of this study. Data for the curves of Figure 24 are computed from:

$$V_v = \sqrt{W/C_D \frac{\rho}{2} \frac{\pi}{4} d^2} \tag{23}$$

where, W = Weight = drag of rotor in vertical descent
C_D = Overall drag coefficient of rotor
d = Rotor diameter, ft

The curves are based on the 4,000-foot, 95°F ambient conditions criterion used throughout this report. Rates of descent for sea level standard conditions can be determined from:

$$\begin{aligned} V_{v_{SL}} &= V_v\sqrt{\rho/\rho_o} \\ &= V_v\ (.898) \end{aligned} \tag{24}$$

A rotor diameter was not specified by Reference 22, however, the rotor as shown (Figure 23), appears to be about 12 feet in diameter. This dimension corresponds to a rate of descent in the region of 30 feet/second (Figure 24) which is higher than would normally be desired for ground-impact recovery.

Increasing rotor diameter to reduce the rate of descent, of course, compounds the rotor installation weight problem and that of the performance of the RPV in the cruise mode due to the increased drag of the stowed rotor.

It is also seen in Figure 24 that rotor diameters, and the other accompanying penalties, would increase to perhaps untenable proportions for the 200-pound class RPV.

Surface Impact Conditions - The nosedown attitude of the RPV as it impacts the ground implies design provisions of some nature to absorb the energy of impact. A simple approach to this problem is to incorporate a

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23. Gessow, A.; Myers, G. C., Jr.; AERODYNAMICS OF THE HELICOPTER, McMillan Co., N.Y.

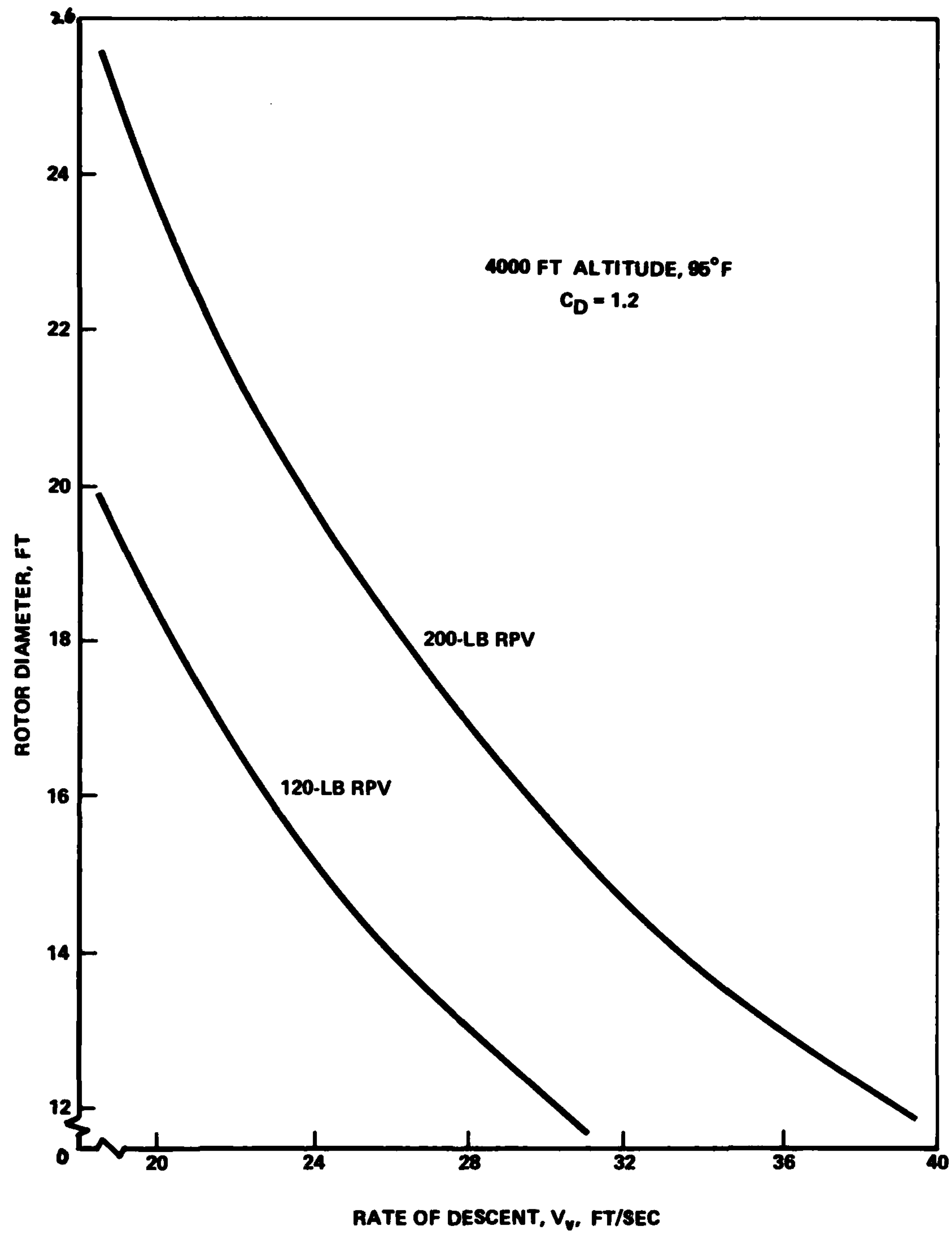

Figure 24. Rotor Diameter versus Rate of Descent

crushable nose. The stroke, h, required to absorb the impact energy can be determined from:

$$h = \frac{WV_v^2}{2g}/(F-W) \tag{25}$$

However, h can be made independent of weight and equation (25) may be expressed in terms of V_v, and load factor, n, which would apply to an RPV of any given weight:

$$h = \frac{V_v^2}{2g}/(n-1) \tag{26}$$

With n = 12 g, the maximum load factor allowed for the other recovery concepts of this study, and V_v = 30 feet/second:

$$h = \frac{(30)^2}{64.4}/(12-1)$$

$$= 1.27 \text{ ft, or } 15.2 \text{ in}$$

Equations (25) and (26) imply that a constant retarding force is applied throughout the stroke distance, or that an ideal damping effect exists. Of course, the real world of impact resisted by airframe structures, crushable or not, does not necessarily include perfect damping; therefore it is probable that g-load peaks of appreciably more than the specified load factor will occur.

The rate of descent, and consequently the computed stroke, h, can be reduced at the expense of a larger-diameter, and therefore heavier rotor. Also, increasing the allowable impact load factor as much as permitted by the critical items of RPV equipment would reduce the stroke required. For example, increasing the rotor diameter to 18 feet, and assuming a 20g-impact load factor:

$$h = \frac{(20)^2}{64.4}/(20-1)$$

$$= 0.33 \text{ ft or } 3.9 \text{ in.}$$

The weight of the 18-foot rotor system for the subject stowed rotor concept, would, no doubt, be disproportionately on the high side.

b. Rotor Deployment Considerations This particular stowed rotor concept would present a special set of problems in that when released, the rotor blades peel off into the wind. The diagrams of Figure 25 implement the following discussion.

For into-the-wind release, getting the blades to the autorotational mode without imposing undue bending and/or torsional loads, or experiencing dynamic difficulties, are the major considerations. Also, the hub would have to be restrained from rotating until the tips fold back past point (B) (Figure 25) in order to clear the wing tips.

The rotor blade deployment problem also has to be viewed in terms of the different speeds of the two RPV classes. For recovery purposes, the velocities for the 120- and 200-pound class RPVs are 50 knots (84.5 feet/second) and 78 knots (131.8 feet/second) respectively, at 4,000 feet altitude, 95°F. These velocities are approximately 1.2 stall speed, which in either case is considerably greater than the final stabilized autorotational speed anticipated. The speeds could be reduced by pulling the RPV up into a stall, with a slight gain in altitude, risking possible conflict between the post-stall behavior of the RPV and symmetrical rotor deployment.

Design problems permitting, it would be desirable to deploy the blades directly from A to C (Figure 25), or slightly beyond where the blades would attain their normal autorotational cone angle, β. Most likely (based on intuitive speculation), the blades would have to be allowed to swing back to a high cone angle at D before appreciable rotation begins. In this way, the rotor would pick up rotational speed more gradually, as the centrifugal effects pull the blades back to the natural cone position at C. The velocity of the RPV would also be more gradually reduced as the drag of the rotor increased during radial extension from D back to C.

c. Surface Impact - When the RPV impacts the ground in a nose-first attitude, the chances of its toppling over are very high. In turn, the rotor striking the ground while still turning due to stored rotational energy would inevitably cause appreciable damage.

d. Wind Effects - The effect of a 20-knot wind on the stowed rotor concept would appear to aggravate the post-impact RPV toppling problem due to striking the ground with a horizontal velocity component. Thus, the rotor would be subject to yet more severe damage due to the sudden rotation of the RPV about its nose.

e. Target Window - Target window conditions for the stowed rotor concept would be similar to that of the parachute studies (subsection 7.2.2) which show considerable latitude in the rotor deployment point with respect to the recovery area. The time required from rotor release until rotation at maximum RPM is achieved would undoubtedly be somewhat greater than that for chute deployment. However, it is still likely that the rotor could be deployed at around 200 feet above the surface.

7.4.3 Conclusions The basic principle of recovery by means of vertical descent using a rotor in the autorotative mode is sound.

The major disadvantages of the stowed rotor concept of Figure 23 is the certain damage that would be incurred by the rotor system due to striking the ground while still rotating as the RPV topples over after impact. Horizontal drift due to wind would increase the damage factor. Other considerations are: (1) a rotor diameter providing a reasonable compromise between descent rate and impact shock attenuation provisions would most probably result in excessive airborne weight, especially for the 200-pound class RPV, (2) a nose structure designed to take impact loads, with or without shock attenuating provisions, would compromise space for existing, or future payload items, and (3) the rotor mounting pylon structure interferes with the engine starting arrangement used for the Aquila XMQM-105-type RPV.

Although based on sound aerodynamic principles, this particular stowed rotor concept's principal deficiency appears to be the high probability of incurring major airframe damage with each recovery operation.

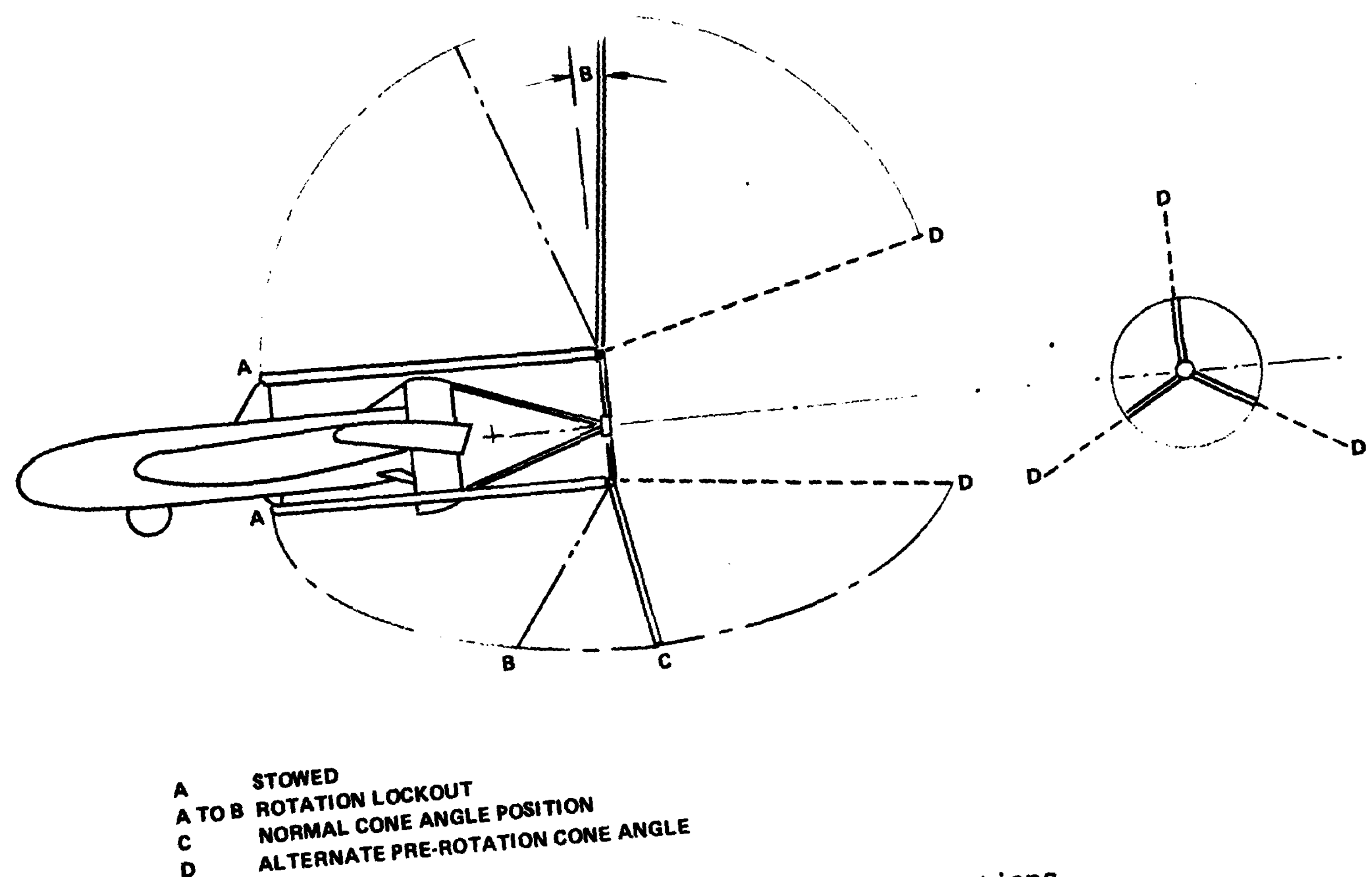

Figure 25. Rotor Deployment Options

7.5 Spin Recovery. Concept I-5A

7.5.1 General. The spin-recovery concept discussed below is taken from Reference 24. Although Reference 24 is a study of RPV's for civil applications, discussion on the use of spin recovery in connection with the U.S. Army/Lockheed XMQM-105 is included. The concept is illustrated in Figure 26.

The intent of the spin recovery scheme is the same as that of the stowed rotor discussed previously in subsection 7.4; that is, to lower the RPV vertically to the ground in a nosedown attitude by means of a rotor in the autorotative mode. The major difference between the two concepts is that the wings themselves serve as rotor blades in the case of spin recovery. The wing-to-rotor blade transfiguration calls for rotating the wing a total of 88 degrees in opposite directions about a pivot axis, perpendicular to the RPV's plane of symmetry. Upon command, forward wing restraining pins are released by means of an electric solenoid. Simultaneously, hard-over aileron action provides the actuating power to rotate the wing into the rotor position. The RPV noses down rapidly as the principal aerodynamic normal forces on the wing change from lift to drag as the RPV goes into the rotor mode. In its basic configuration, the wing span and rotor diameter are the same (12 feet). For lower rates of descent the rotor diameter can be increased with extendable rotor flaps as shown in Figure 26. The particular flap configuration shown increases the rotor diameter to 18 feet.

7.5.2 Analysis. The rates of descent stated in Reference 24 for the spin recovery RPV are:

Rotor Diameter, ft	12	18
V_v, ft/sec	28.7	20.0

Sea level standard conditions are assumed.

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24. Aderhold, J. R., Gordon, G., Scott, G. W., CIVIC USES OF REMOTELY PILOTED AIRCRAFT, LOCKHEED MISSILES & SPACE CO., INC., Contract NAS 2-8935 for Ames Research Center, NASA, Moffett Field, Ca., July 1976.

A cursory analysis, in addition to the data given in Reference 24, indicates that the rotational speeds would be about 400 and 287 RPM for the 12-foot, and 18-foot rotors, respectively.

Incremental weights estimated for the spin recovery system in Reference 24 are:

Reinforcement Structure	8.7 lb
Two solenoids	1.5 lb
Two rotor flaps	9.5 lb
	19.7 lb

7.5.3 Conclusions. Comments under the topics of Surface Impact, Wind Effects, and Target Window discussed (in subsection 7.4.2) for the stowed rotor would generally apply to the spin recovery concept. Likewise, the comments under subsection 7.4.3, Conclusions, would also apply except that the spin recovery configuration does not interfere with the RPV's engine starting arrangement.

In common with the stowed rotor, the spin recovery concept's principal disadvantage appears to be the imminence of major airframe damage with each recovery operation.

7.6 Capture Net, Concept II-1

7.6.1 Introduction. The term "capture net" is used here as a generic title that covers four other types of recovery nets, discussed in the following subsections:

- 7.6.2 Fixed, or Articulated Net, Concept II-1A
- 7.6.3 Traveling Net, Concept II-1B
- 7.6.4 Traveling Net plus Impact Platform, Concept II-1C
- 7.6.5 Inflatable Frame/Net, Concept II-1D

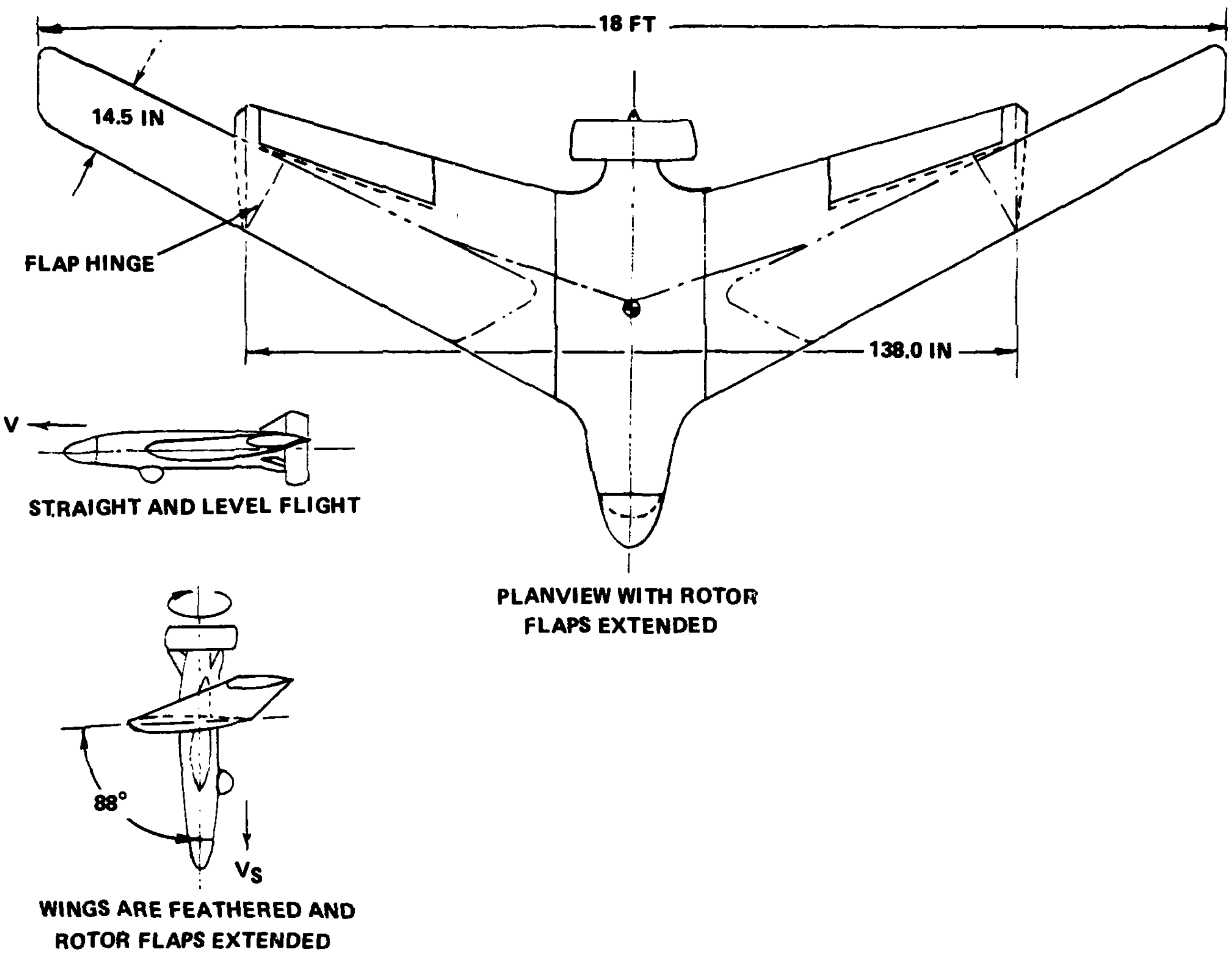

Figure 26. Spin Recovery RPV

7.6.2 Fixed/Articulated Net , Concept II-1A

a. General

The fixed recovery net concept represents the simplest form of recovery system, in that it consists of a net fixed around its periphery to a more or less rigid frame. Generally the frame would be tilted away from the direction of flight of the Mini-RPV, as shown in Figure 27, to provide a bag effect to capture the RPV. The energy-absorbing qualities of this arrangement depend mostly on a short lived momentum exchange between the mass of the net and that of the RPV, and the elasticity of the net.

Making the net longer and baggier would require some form of auxiliary support for the net, or high mounting stanchions to keep the RPV from striking the ground.

A natural product improvement for the fixed net is to articulate the stanchions to provide more stroke as shown in Figure 28. The energy-absorbing elements in this case include the net, the inertia of the frame, and undoubtedly an energy absorber of some type to dampen the whole unit.

An articulated net concept similar to that of Figure 28 is presented in Reference 25.

b. Conclusions

The fixed/articulated net concept could conceivably be, and may have been, employed for recovery energy requirements that match its capabilities. However, the considerably longer strokes found necessary for the 120-pound, and especially the 200-pound class RPVs, are apparently handled more satisfactorily with the "traveling net" types described in the following paragraphs.

7.6.3 Traveling Net, Concept II-1B

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25. Smyth, T. PROPOSAL FOR RECOVERY SYSTEM OF REMOTELY PILOTED VEHICLES, Parks College, Canokia, Ill., 25 September 1976.

a. General

Traveling Net, as used here, signifies a form of capture net in which the net breaks temporary restraints holding it to a frame or vertical stanchions, and travels against snubber lines connected to some form of energy absorber. The RPV remains in the net at the end of the recovery sequence.

A traveling net concept suited to the 120- to 200-pound class RPVs is depicted schematically in Figure 29. As will be seen, the net slides along guide cables stretched between stanchions. The upper corners of the net slide on Teflon slippers. The lower corners of the net are attached to a shock chord bungee, the upper end of which is also attached to slippers. This arrangement forms a bag to retain the RPV at the end of the system travel.

In the ready position, the upper corners of the net are restrained near the upper ends of the two stanchions by breakaway ties. The lower corners of the net, to which the bungee chords are attached, are looped over a smooth, tapered spike such that the tension (bungee chord) restrains the net until the RPV impacts the net.

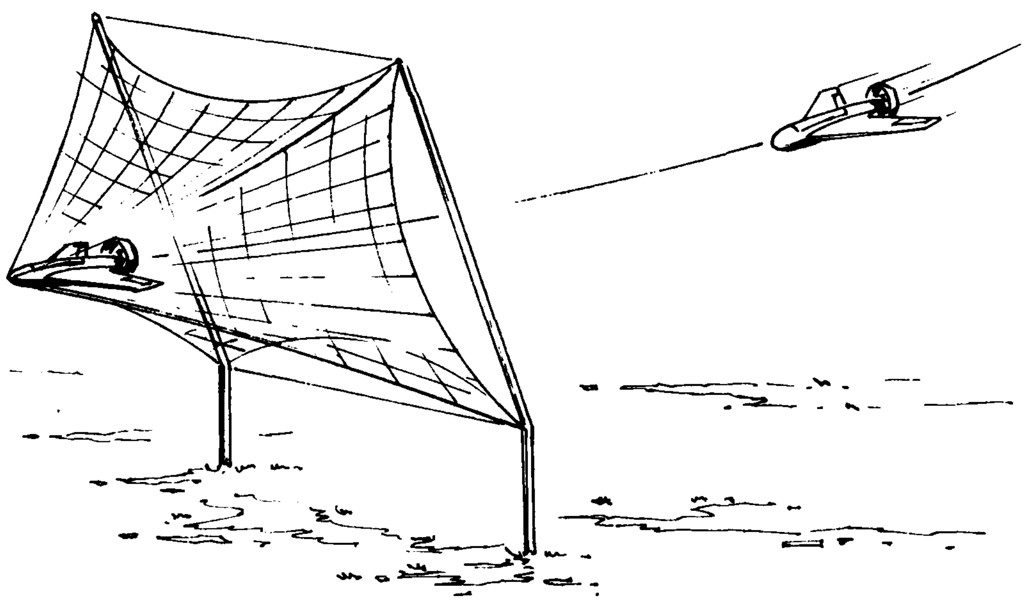

Figure 27. Fixed Recovery Net

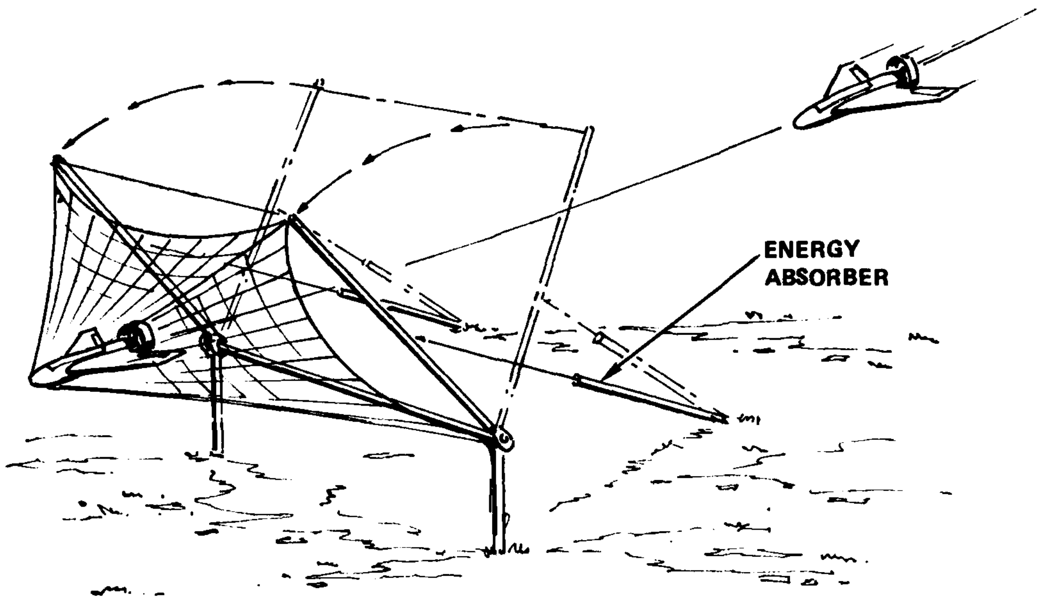

Figure 28. Articulated Recovery Net

A snubber line is tied to the slipper at each upper corner of the net, and a snubber line is tied directly to each lower corner of the net. These lines run over a system of pulleys converging at a tape wound onto a reel that is attached to the shaft of a rotary water brake energy absorber.

After the initial stretch of the net occurs at impact, the breakaway ties at its upper corners release, and the lower corners slip off the spike. The taut bungee chord picks up the lower corners of the net closing the bag on the RPV as it travels.

The RPV is retrieved from the net by lowering the guide cables on which the net travels. The guide cables are attached at their apex to a winch line which passes over a pulley attached to the top of the stanchion, then down to a hand-operated winch.

Prototype hardware for a traveling net recovery system is shown in action in Figure 30. The photo sequence depicts the recovery of a 167-pound Mini-RPV (Reference 26).

b. Analysis

A typical retarding force versus stroke curve for an earlier test of the traveling net system for a 150-pound RPV entering at 60 knots (kinetic energy = 23949 foot-pounds) is shown in Figure 31.

For the first few feet of travel, while gathering up the inherent slack in the system, the retarding force is almost constant at about one-quarter its peak value. The shape of the curve the rest of the way is largely a reflection of the characteristics of the water brake energy absorber.

The peak retarding load of about 1250 pounds represents an instantaneous load factor of 8.3 g, and the average load of 680 pounds corresponds to a load factor of 4.53 g; the efficiency is 0.54.

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26. ANON, RECOVERY SYSTEM, SURFACE MOUNTED TRA SPECIFICATION NO. 26259-102, TRA, San Diego, Ca., 21 November 1974.

The energy level of the 167-pound RPV (Figure 30), at a 70-knot approach speed, is 36204 foot-pounds. The observed total stroke of the traveling net was 38 feet The average force is:

$$\begin{aligned} F &= 36204/38 \\ &= 952.7 \text{ lb} \end{aligned}$$

and the average load factor would be

$$\begin{aligned} &952.7/167 \\ &= 5.7 \text{ g} \end{aligned}$$

based on a ratio of average-to-peakloads of 1.83, as indicated in Figure 31. The maximum instantaneous load factor for the 167-pound RPV can be estimated at:

$$\begin{aligned} &5.7\ (1.83) \\ &= 10.4 \text{ g} \end{aligned}$$

c. Conclusions

The traveling net is seen to be a credible Mini-RPV recovery concept confirmed by test hardware.

Improvements in performance could be made for the particular system studied above by reducing the instantaneous maximum deceleration load factors by additional development work on the energy-absorbing system. However, it appears that the peaks can be held to less than the 12g design criterion without additional development cost and time.

7.6.4 Traveling Net Plus Impact Platform, Concept II-1C

a. General

The traveling net plus Impact Platform (I.P.) concept is defined as a capture net that falls on a resilient platform after capturing the RPV and traveling its full stroke distance.

An early demonstration of the traveling net and I.P., concept installed on a Navy ship is shown in Figure 32 (Aviation Week, 15 September 1975). The Mini-RPV used in the trials is said to weigh 50 pounds. Its entry speed at the net is unknown.

A traveling net and I.P. recovery system for the Aquila-

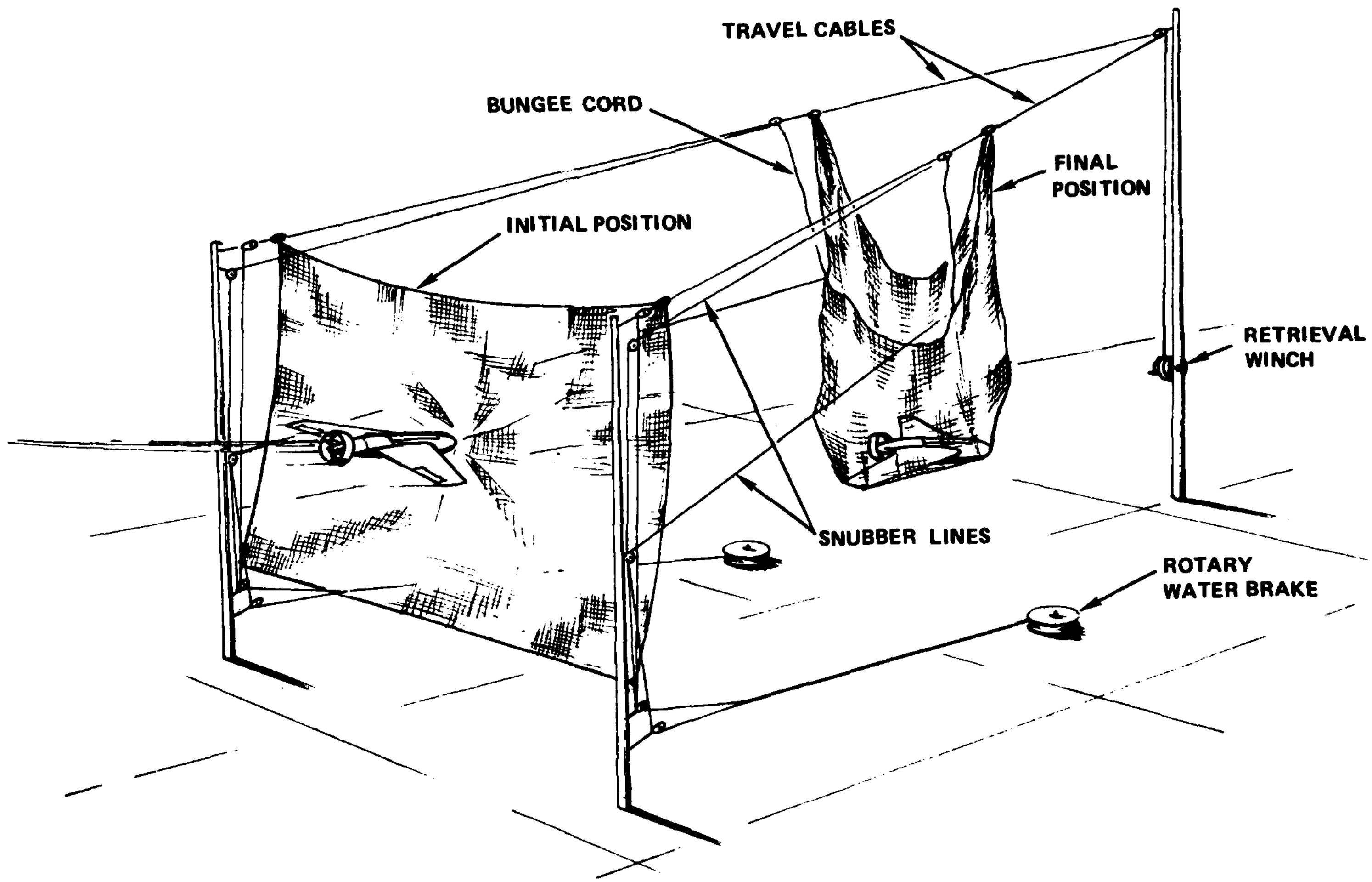

Figure 29. Schematic, Traveling Net Concept

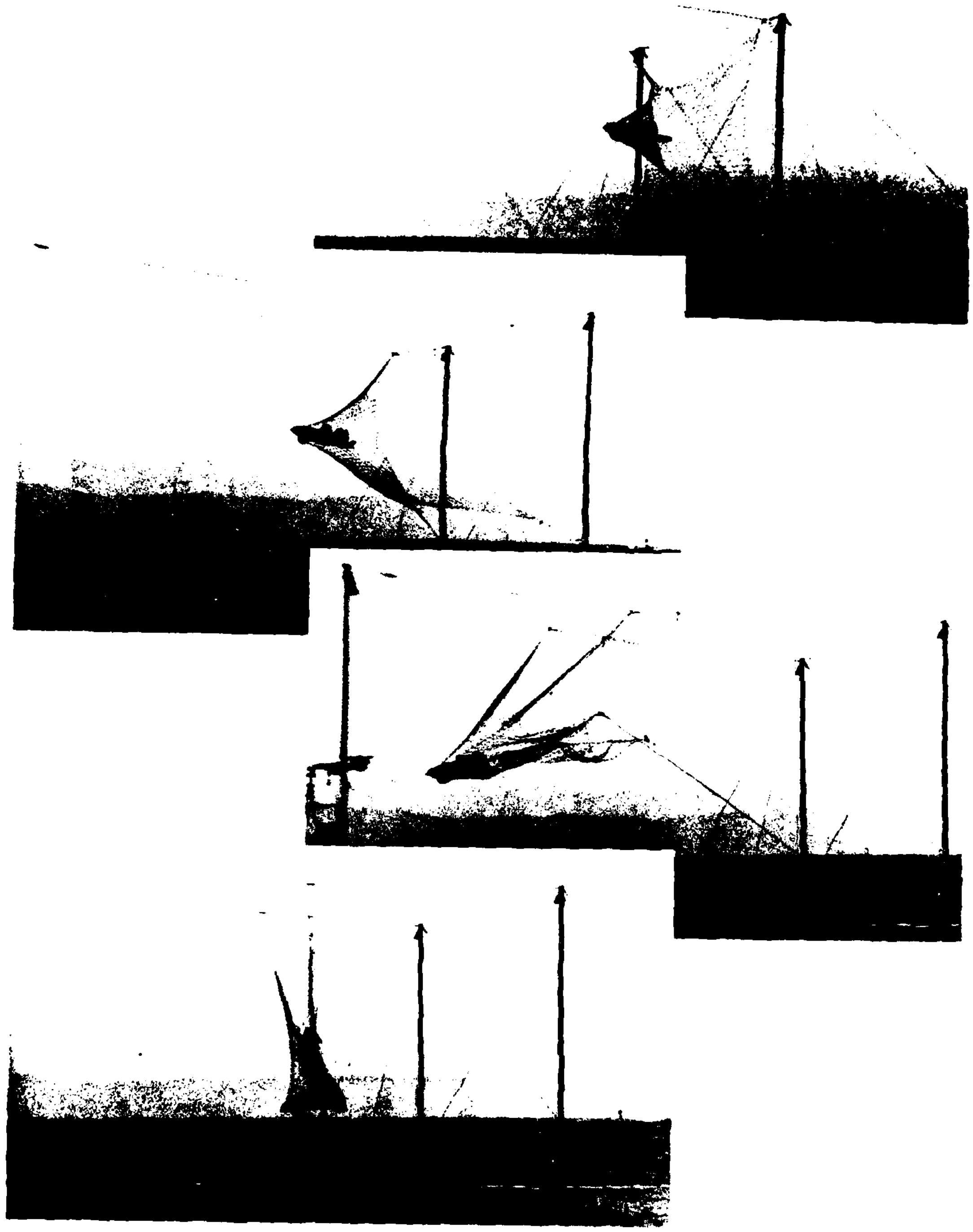

Figure 30. Traveling Net Recovery Sequence

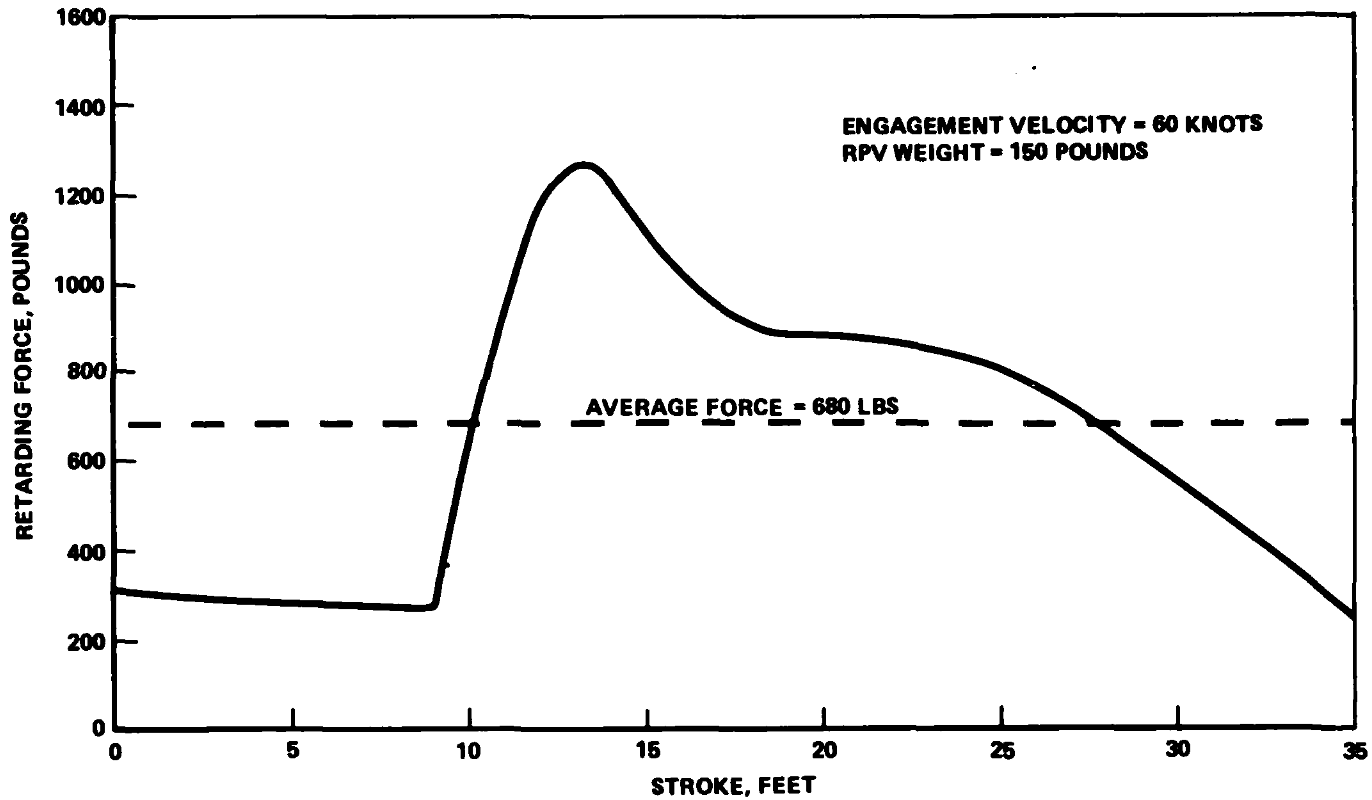

Figure 31. Force/Stroke, Traveling Net

type Mini-RPV is shown in Figure 33. The capture net in this instance is fabricated of multiple vertical straps or ribbons of nylon or similar material with horizontal straps at the edges and one across the center of the net. This type of net, similar to the emergency barricade net used on aircraft carriers, provides a favorable load distribution along the wing of the RPV when it impacts the net. The energy-absorbing system for the ribbon net employs water turbine dampers in a manner similar to the traveling net of Figure 29. In this particular installation, the net dimensions are 35 feet wide by 15 feet high.

The impact platform, about 60 feet long, is made of resilient ribbons similar to those used in the net.

Another form of impact platform is the air-cushion type shown in Figure 34. The air cushion shown is about 35 by 50 feet, by 5 feet high. It is constructed of very light nylon (4 oz/yd) sealed with an elastomeric material. The air cushion is inflated to a very low pressure by a small reciprocating engine-driven blower. Large blow-out valves modulate the cushion pressure during the impact cycle.

b. Analysis

Meager preliminary data available on the performance of a capture net with a tape, or ribbon type platform and with an inflatable air bag platform are tabulated below. The air vehicle, similar to the XMQM-105, weighed about 138 pounds (Reference 27).

Resilient Tape-Platform

V Knots	Kinetic Energy, ft-lb	n, Vertical g	n, Horizontal g
48	14200	6.5	3.5
48	14200	4.0	3.0
50	15411	6.0	4.0
63	24467	6.0	4.6

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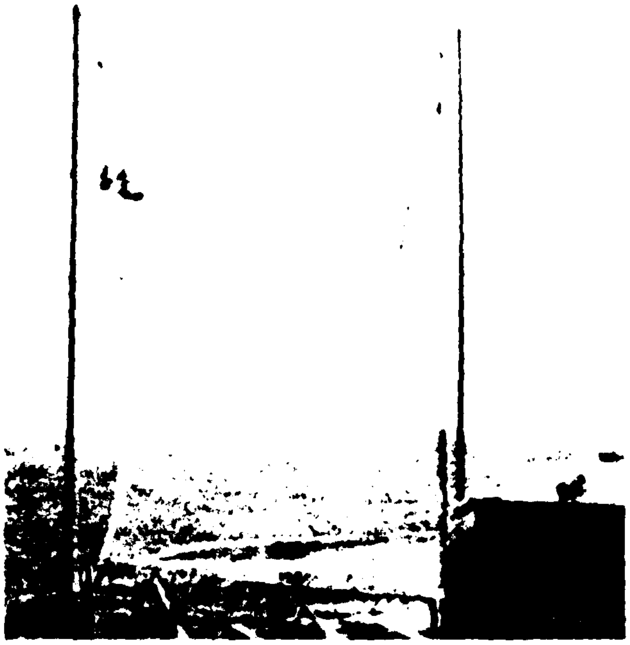
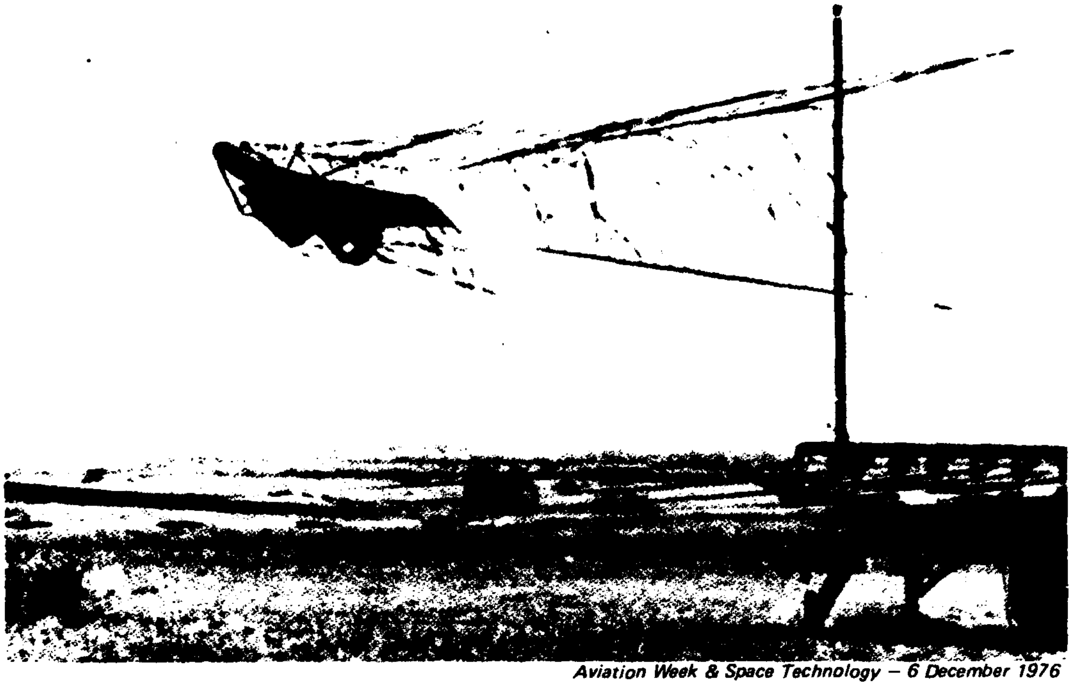
27. ANON, MISCELLANEOUS TEST DATA, USAAMRDL, Fort Eustis, Va., November 1976.



Aviation Week & Space Technology – 15 September 1975

Figure 32. NSWC Sea Trials, Traveling Net plus I.P.



Aviation Week & Space Technology – 6 December 1976

Figure 33. U.S. Army, Aquila RPV, Traveling Net plus I.P.

Figure 34. U.S. Army/DSI Traveling Net + I.P. (Air Cushion)

Inflatable Air-Bag

60	22192	6.0	6.5
62	23697	8.0	6.5

c. Conclusion

The traveling net and I.P. concept, like the traveling net concept of subsection 7.6.3, is also seen to be a credible Mini-RPV recovery concept confirmed by test hardware.

7.6.5 Inflatable Frame/Net, Concept II-1D

a. General

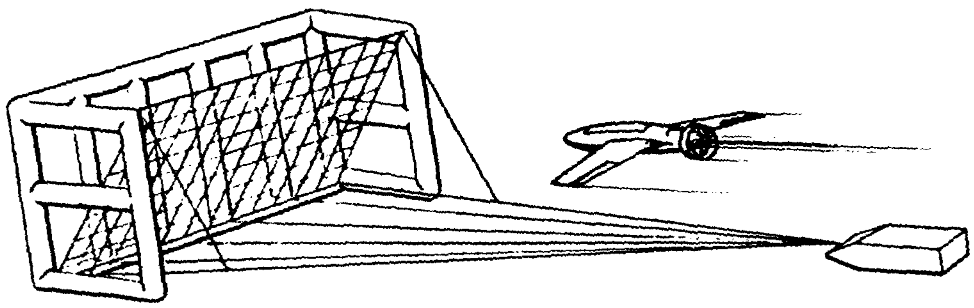
The inflatable frame/net concept taken from Reference 21 and depicted in Figure 35 is obliquely a version of the traveling net plus impact platform concept (subsection 7.6.4). It includes a capture net supported by an inflated tubular frame made of resilient material. The inflated frame would become the impact platform after the RPV is captured by the net and falls on the frame.

A noteable difference between the two concepts is that the impact platform and net for the inflatable frame/net system travel together after the RPV falls on the frame, some energy would be absorbed by the frame/net assembly sliding along the ground or other surface. The major part of the energy would be absorbed by a weighted sled-type device tied to the frame/net complex by a series of fanned out lines. The lines would be configured to stabilize the frame inlet unit as it traveled, and to prevent the RPV from spilling out.

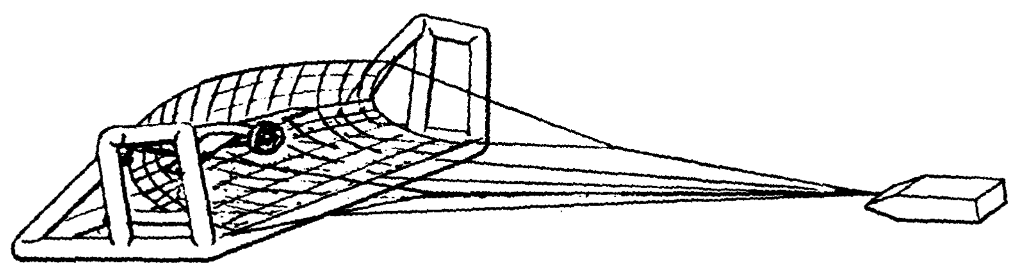
A suggested change to the concept as presented is the addition of a force damper placed between the drag sled and the inflatable frame/net assembly.

b. Analysis

The inflatable frame/net recovery concept of Figure 35 presents several design and analytical problems that could only be solved by a combination of sophisticated analysis (still fraught with assumptions) and experimental work. However, an idea of the character of the system can be gained by some simple estimates done



(a) APPROACH



(b) DECELERATION

Figure 35. Inflatable Frame/Net Recovery System

in steps. Estimates are made for both the 120- and the 200-pound class Mini-RPVs.

First, the size and weight of the assembly is estimated. The frame shown in Figure 35 is assumed to be 25 feet wide, 15 feet high (center line dimensions), and 8 feet long. The inflated tube diameter is 15 inches for the 120-pound class RPV, and 18 inches for the 200-pound class RPV. These assumptions result in the following parameters:

	120-lb RPV	200-lb RPV
Volume, ft^3	167	261
Surface Area, ft^2	669	836
Weight, lb		
Frame	125	157
Net	20	25
Air	13	21
Total Weight	158	203

The frame weight is based on rubberized fabric, 0.025-inch thick at 27 oz/yd. Air weight is based on a 1-psi gage.

A model for computing the travel sequence of the inflatable frame/net assembly after impact by the RPV is illustrated in Figure 36. An addition to the original concept noted above is a damper placed between the drag sled and the apex of the lines running to the frame/net assembly. This damper could take the form of a heavy chain folded on the ground such that the load increases gradually, a pneumatic or hydraulic device, or a drag sled unit made in segments tied in such a manner as to modulate the applied drag force. In the computations a hypothetical damper is assumed to provide a linear force build-up.

The travel sequence of the frame/net unit and the weighted drag sled is estimated as indicated by steps (a) through (d) in Figure 36. In step (a), the collision (exchange of momentum) of the RPV and frame/net assembly is assumed to build up force linearly throughout a distance, ℓ_3, at which point the two mass systems come to a common velocity. In the next step, (b), the damper then extends with a linear build up to the length ℓ_2, after which the line tension is assumed to build up to a load equivalent to 12gs, in terms of the weight of the RPV plus that of the frame/net assembly.

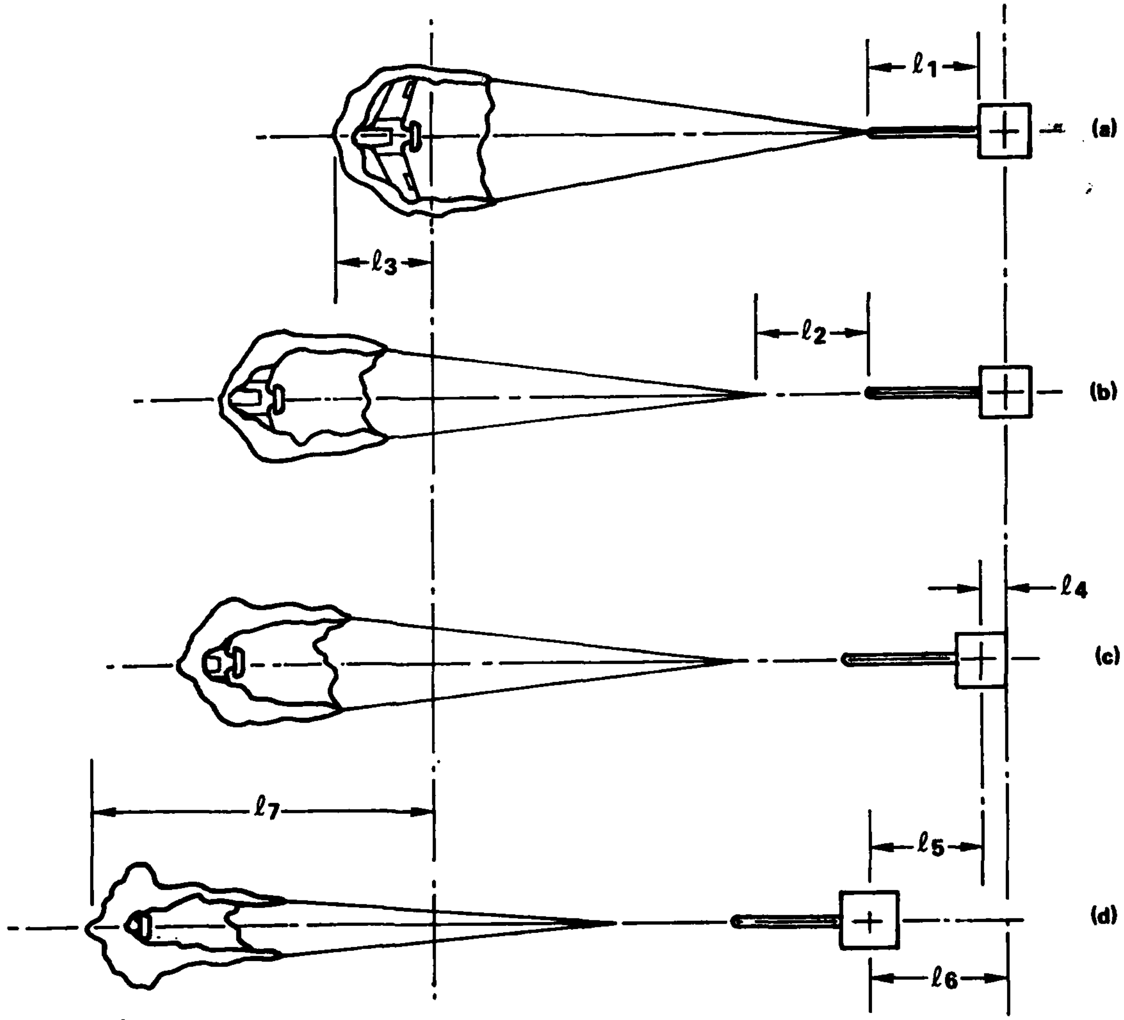


Figure 36. Travel Sequence Model, Inflatable Frame/Net

In step (c) the combined masses of the RPV and the frame/net assembly decelerates and the drag sled accelerates to reach a common velocity in a very short distance.

In step (d) the total mass of all components is assumed to slide to a stop under the influence of a constant retarding force based on a friction coefficient of μ = 0.5.

A summary of the values computed on the basis of the above assumptions is given below:

	120-lb RPV	200-lb RPV
Initial Velocity, ft/sec	84.5	131.82
ℓ_2, ft	5.0	5.0
Step (a)		
(1) Common Velocity, ft/sec	49.7	87.3
(2) Kinetic Energy, ft/lbs	11046.3	47692.2
(3) ℓ_3, ft	10	15
Step (b)		
(4) Damper Max. Load, lb	500	1774
(5) Work Done, ft-lb	1250	15735
(6) K.E. of (2) - (5), ft-lb	9796	31957
(7) Common Velocity, based on (6), ft/sec	46.8	71.4
(8) Load in Line (12 g), lb	3456	4836
(9) Sled Weight, lb	1000	3548
(10) Friction of Sled = W (0.5), lb	500	1774
(11) Net Force = (8) - (10), lb	2956	3062
Step (c)		
(12) Sled g = 2956/1000	2.956	0.863
(13) Common velocity, ft/sec	19.5	18
(14) ℓ_4, ft	2.0	5.8
Step (d)		
(15) ℓ_5, Distance to slide out, ft	11.8	10.1

Distances

(16) Drag Sled, ft

$\ell_6 = \ell_4 + \ell_5$

$= (14) + (15) =$	13.8	15.9

(17) Net/Frame Assembly, ft

$\ell_7 = \ell_2 + \ell_3 + \ell_6$

$= 5.0 + (13) + (16) =$	28.8	48.6

c. Conclusions

One of the first problems that would have to be resolved for this concept is to configure the inflated frame to provide suitable shock attenuation characteristics to withstand the impact forces of the RPV dropping on it. The tubular frame-work as presented would provide an infinite variety of impact "foot prints" for the RPV.

With the tubular members of the frame interconnected as a single pressure vessel, the retarding forces resulting from pressure increases (volume change) to resist the RPV's impact would be very small. A system of internal bulkheads with suitable orifices could divide the inflated frame into compartments, thus providing improved shock attenuation characteristics.

Another pneumatic design problem to be considered is to achieve a suitable compromise between the inflation pressures required to rigidize the frame and that required for energy absorption.

If the inflatable frame/net recovery system is placed on the ground in the recovery zone, areas to accommodate the travel lengths, ℓ_6 and ℓ_7, would have to be prepared, unless the terrain was suitably smooth. Also, in order to meet the wind shift requirements, large circular areas would have to be prepared.

An alternative to setting the recovery system on the ground would be to provide platforms on trucks to make the system mobile.

Variation in terrain conditions and weather conditions (water, ice) would make the performance of a ground installed inflatable frame/net erratic and at times unusable. And to some extent the behavior of the drag sled would be affected by weather conditions even when mounted on a platform.

The mechanical problems envisioned for the inflatable frame/net recovery system could undoubtedly be solved given development time and funds. However, the concept as presented does not appear to be suitable for deployment in the Army tactical environment anticipated for Mini-RPV operations.

7.7 Inclined Ramp, Concept II-2

7.7.1 Introduction. The basic concept of the inclined ramp (Reference 21) used for the recovery of Mini-RPVs is initially attractive because of its inherent simplicity. In its basic form the inclined ramp is, in effect, an uphill runway where energy is dissipated by friction as the RPV skids to a stop. Two types of inclined ramps are reviewed in the following paragraphs. The first is the basic form in which all energy is dissipated as friction, and the second type would incorporate auxiliary decelerating devices to shorten the overall length of the ramp. These are identified as:

- 7.7.2 Inclined Ramp, Friction, Concept II-2A
- 7.7.3 Inclined Ramp Plus Auxiliary Deceleration Devices, Concept II-2B

It is interesting to note that the inclined ramp (with some liberty taken in the definition of an inclined ramp) is not necessarily a space-age innovation, like a few of the other recovery concepts examined in this study. An earlier patented thought on the subject is illustrated in Figure 37. This concept relates to Concept II-2B, including auxiliary deceleration devices in the form of hooks attached to its skid landing gear to engage the net-type ramp.

7.7.2 Inclined Ramp, Friction, Concept II-2A

a. General

A basic inclined ramp which depends entirely on friction to decelerate the Mini-RPV being recovered is illustrated in Figure 38. The ramp would consist of suitably spaced resilient tapes (ribbons) of nylon or similar material stretched between two supporting frames. The construction of the ramp would be similar to that of one of the impact platforms discussed in subsection 7.6.4.

F. SMITH.

AIRPLANE LANDING AND LAUNCHING EQUIPMENT.

APPLICATION FILED OCT. 9, 1917.

1,306,860. Patented June 17, 1919.

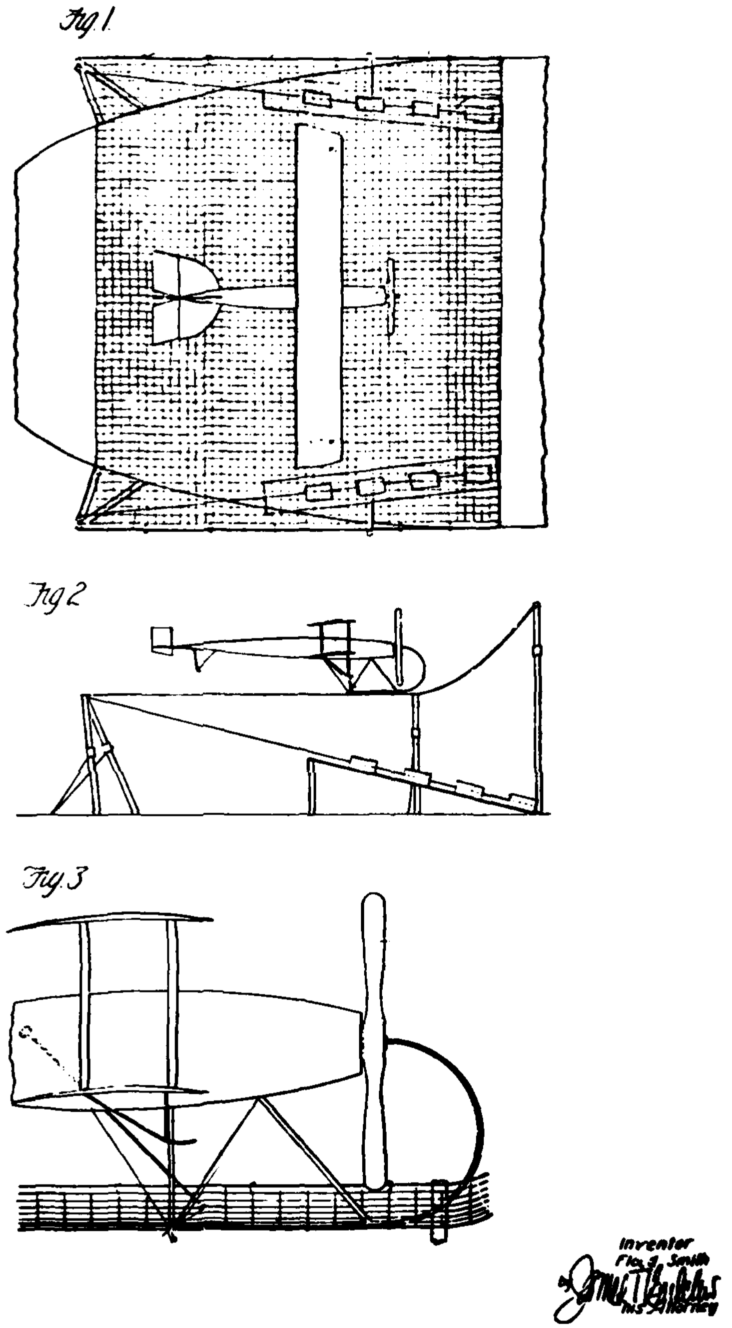


Figure 37. Early Patent, Inclined Ramp

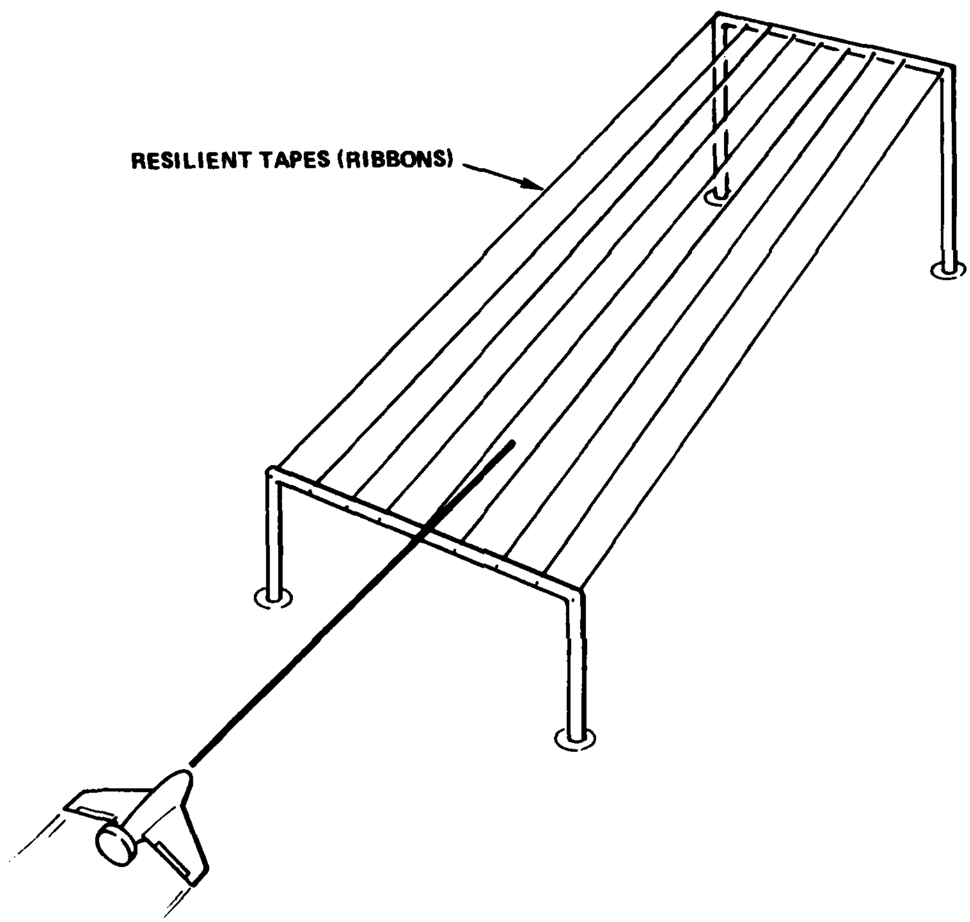


Figure 38. Inclined Ramp Recovery Concept

In some cases mesh-type nets have been considered for this purpose. However, the tape-type construction provides a smoother surface overall, eliminating the deleterious "lumps" caused by the cross chords of a net, and can provide directional steering for the RPV. The use of resilient material implies that the inclined ramp would deflect noticeably under its own weight plus that of the RPV.

b. Analysis

Ramp Characteristics

The angle of inclination of the ramp would be a compromise among several factors. Some of these are: (1) the retarding force available due to the rearward acting weight component of the RPV; (2) striking the ramp at too steep an angle thus risking high impact 'g' peaks and/or skipping and tumbling of the RPV (skipping to some extent is probable in any case); and (3) excessively tall support frame-work at the high end of the ramp.

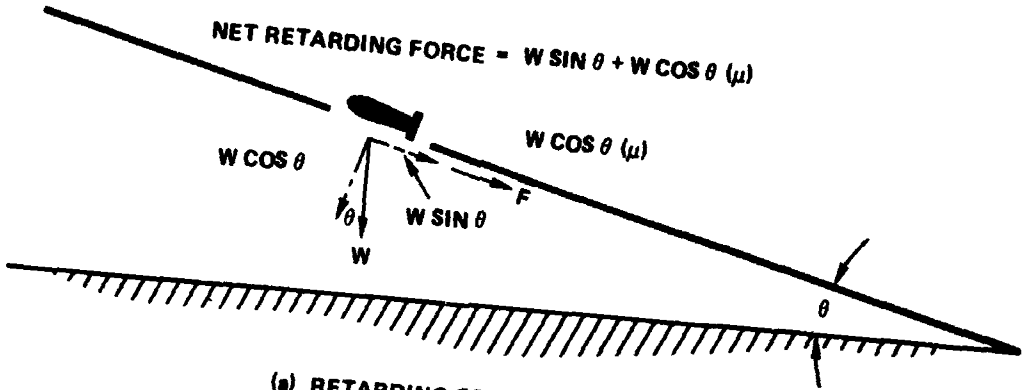
In addition to the weight component providing a retarding force, a friction force due to the normal weight component applied to the ramp also helps to decelerate the RPV (Figure 39 (a)).

Depending on the shapes that the deflected ramp material would take as the RPV traverses the length of the ramp, the instantaneous retarding forces can be expected to vary (Figure 39 (b)) from that of the plane-ramp assumptions made above. The ramp slopes could presumably be less at the beginning (1), about the same in the middle (2), and steeper at the end (3), than the plane-ramp surface.

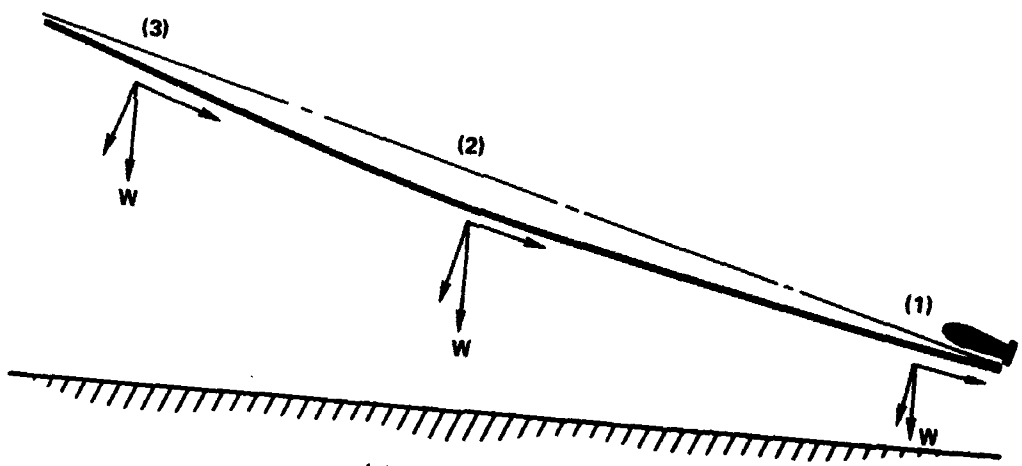
An in-depth analytical solution to estimate the required ramp length to decelerate the candidate RPVs, involving all applicable variables, is beyond the scope of this study. However, a simplified analysis based on a plane-ramp assumption is presented to give an order of magnitude of the distances required to decelerate the 200-pound RPV as "worst case" conditions for ramp lengths.

The following equations are used to determine the distance to decelerate at various ramp angles:

$$-Ft = m \left(V_1 - V_o\right) \tag{27}$$



(a) RETARDING FORCE, PLANE—RAMP



(b) DEFLECTED RAMP

Figure 39. Ramp Analytical Configurations

where $F = F_1 + F_2$
and $F_1 = W \sin \theta$
$F_2 = W\mu \cos \theta$

for the time to decelerate

$$t = m\,(V_1 - V_o)/-F \tag{28}$$

and distance to decelerate

$$\ell_d = \frac{(V_o + V_1)}{2}\, t \qquad (2) \tag{29}$$

Curves shown in Figure 40 are plotted for calculated run-out distances versus ramp angle for 10-degree to 25-degree slopes for the 200-pound Mini-RPV, with $\mu = 0.3$ and 0.5. Typical average longitudinal load factors are $n = 0.63$ g for the 20-degree ramp and $n = 0.47$ g for the 10-degree ramp.

It is seen from Figure 40 that the distances required to decelerate the RPV by skidding up the inclined plane-ramp are relatively long. As noted above, increasing the ramp angle increases the risk of high initial impact loads and/or bouncing and tumbling of the RPV. The ramp angle, θ, used for the remainder of the calculations of this study is 10 degrees.

Using the 10-degree ramp slope for the 200-pound-type RPV, we read from Figure 40 run-out distances, ℓ_d, of 575 feet at $\mu = 0.3$ and about 410 feet for $\mu = 0.5$.

In order to assure adequate vertical height of the target window to allow for navigation errors, additional ramp length over that shown in Figure 40 would have to be provided. For a level flight approach over the edge of the ramp, each foot of height above point "A" would add 5.76 feet of length to the ramp, or 46 feet for a window 8 feet high.

Other increments additive to the ramp length are indicated in Figure 41. No estimates for the lengths of these increments are made since it appears that the length of the basic ramp would be excessive without adding the increments.

The width of the inclined ramp could be approximated by the lateral tolerance of the terminal guidance system and the span of the Mini-RPV. However, other width factors would have to be determined experimentally, such as assuring that the RPV did not travel too close to the edge of the ramp, risking the possibility of dumping over the side.

For the Aquila-type RPV with a wing span of about 12 feet and with ±3 foot lateral tolerance for the terminal guidance system plus some free edge distance, (2 feet/side), the ramp would be a minimum of 22 feet wide.

Protrusions on the bottom of the vehicle would help guide it between two ribbons, thus alleviating the problem of steering a straight course up the ramp.

c. Conclusions

The II-2A version of the inclined ramp concept appears to be generally incompatible with the intended use of recovering Mini-RPVs in a tactical environment. Being inordinately large, about 10,000 feet^2, the ramp would present a very large visual signature as observed from the air and also from the ground. It would be unwieldly for erecting, knocking down, and moving to meet prevalent wind directions.

Other problems to consider are: rigging the long, elastic ramp tapes to give uniform runway conditions; encountering resonant conditions due to wind; ice accretion; and retrieving the RPV from the high ramp.

7.7.3 Inclined Ramp Plus Auxiliary Decelerating Devices, Concept II-2B

a. General

The employment of auxiliary deceleration devices in connection with the inclined ramp would shorten the runout distances to perhaps more tenable lengths than indicated in the basic inclined ramp discussion in subsection 7.7.2.

The auxiliary decelerating devices could be applied in a number of ways. However, as long as the strict definition of the inclined ramp is adhered to, the total length of the installation would probably be greater than, say, the Traveling Net Plus Impact Platform (subsection 7.6.4).

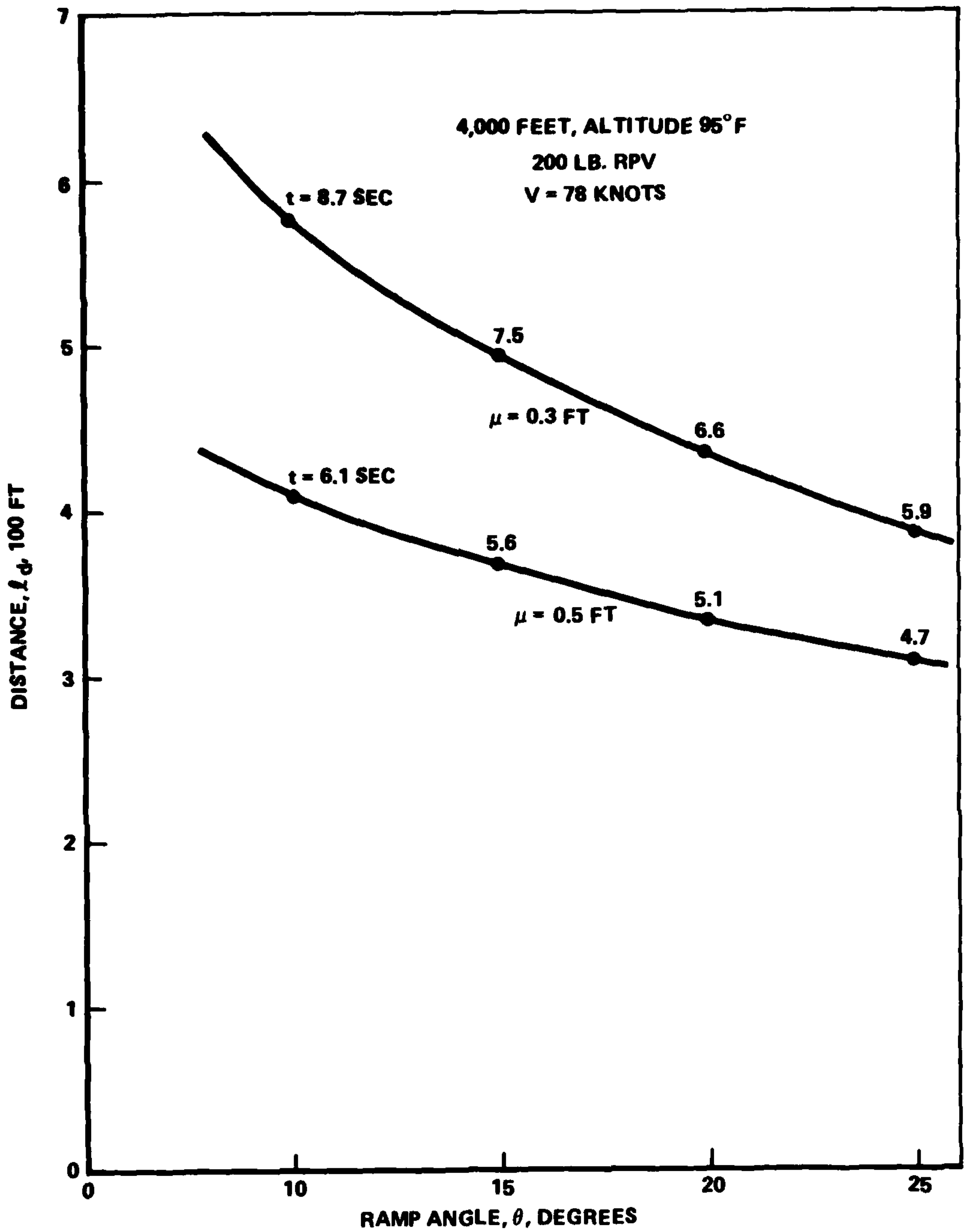
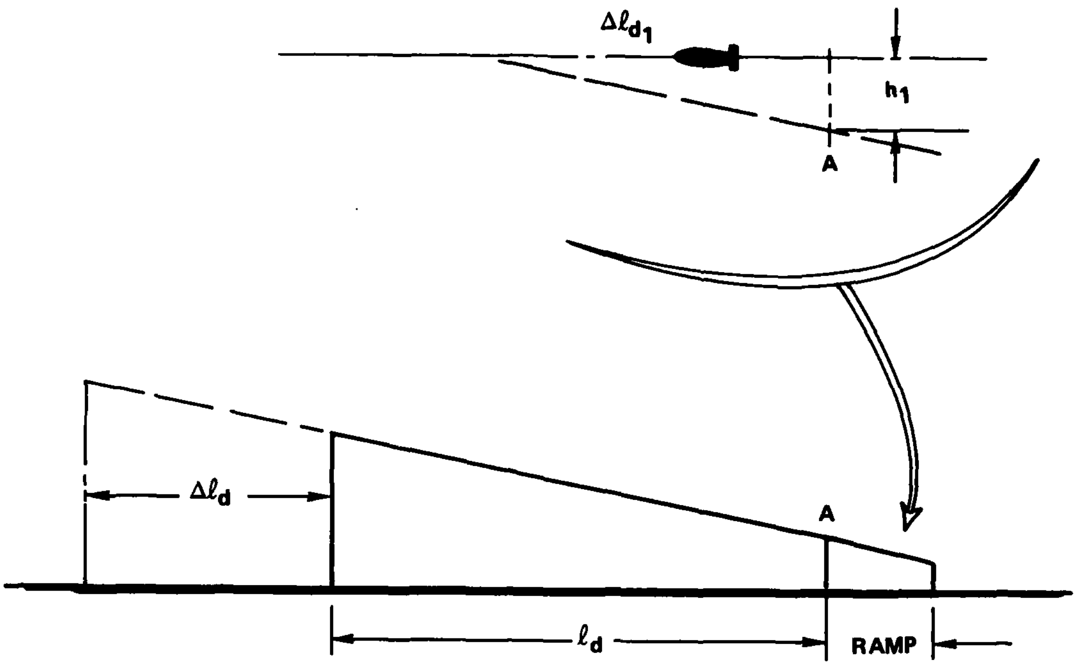


Figure 40. Deceleration Distance versus Ramp Angle θ



ℓ_d = CALCULATED IDEAL DECELERATION RUN-OUT

ADDITIVE INCREMENTS

$\Delta \ell_{d_1}$ = DUE TO TARGET WINDOW WEIGHT, h

$\Delta \ell_{d_2}$ = Δ FOR REAL WORLD VS IDEAL RUN-OUT

$\Delta \ell_{d_3}$ = CLEARANCE: TO PREVENT RPV STRIKING SUPPORTS AT FAR END OF RAMP

$\Delta \ell_{d_4}$ = DEFLECTOR RAMP

$\Sigma = \Delta \ell_d$

Figure 41. Additive Ramp Length Increments

b. Analysis

Ramp Characteristics

The ideal runout distances for a ramp with a 10 degree inclination for the 200-pound class RPV are estimated by using equations (27) and (28), except that

$$F = F_1 + F_2 + F_3$$

where F = the retarding force applied by the decelerating device. The applied retarding forces are assumed to be equivalent to 3, 6, and 12 g.

$\mu = 0.3$

n, g	3	6	12
ℓ_d, ft	77	41.7	21.6
t, sec	1.18	0.633	0.328

The length allowance to provide an 8-foot target window height is 46 feet, as determined in subsection 7.7.2 (b). Adding this to the above distances, the totals become:

ℓ_d + 46 ft	123	87.7	67.6

The other additive increments of length discussed in subsection 7.7.2, Figure 41 would also apply to the ramp equipped with auxiliary deceleration devices. Also, other increments to be considered are; (1), the "stretch out" length of the RPV and trailing hook (if used) and (2) the inherent slack found in most real-world deceleration systems. However, these two items can not be held against the ramp concept in terms of comparison since they exist, as they apply individually, for the Traveling Net Plus Impact Platform and the Wire plus Impact Platform concepts (subsections 7.6 and 7.12).

c. Conclusions

The addition of auxiliary deceleration devices to the inclined ramp recovery concept would reduce the size of the installation to perhaps manageable dimensions; although it appears that it would still be somewhat longer than comparable systems (Concepts II-1B and II-7B). It is also seen that the manner in which the auxiliary deceleration scheme is applied would have to be carefully chosen so that the ramp concept would not revert to comparable concepts.

One scheme that might be workable is to equip the RPV with a relatively short, extendable hook that engages arresting cables placed slightly below the surface of the ramp. The chances of the tapes preventing the hook from projecting below the surface appear to be remote. However, the "target window" height would have to be increased to account for the projected vertical dimensions of the hook. This in turn implies another length increment to the ramp length.

Another possibility is to use a retrorocket to decelerate the RPV after touchdown. However, even at n = 12 g this would still require a basic ramp length of about 67 feet, plus the incremental lengths previously discussed.

It appears that the inclined ramp concept installation with auxiliary deceleration devices would be longer than similar concepts such as the Traveling Net and Impact Platform and the Wire Plus Impact Platform Concepts. The extra length, of itself, would not necessarily make the ramp concept unacceptable. There appears to be no advantage of the inclined ramp over, comparable concepts, and the problems related to the ramp's inherently less-than-positive capture capability (due to the possibility of skipping, bouncing, etc.) are outwardly unfavorable and probably would require considerable development time and cost to solve.

7.8 Rotary (Carousel), Concept II-3A

7.8.1 General. The rotary (carousel) recovery concept would provide a means of decelerating an RPV and bringing it to rest by converting linear motion into circular motion for energy dissipation and retrieval purposes.

The basic rotary concept can be traced back at least 55 years by means of patent records. Patent number 1,383,595, J.S. Black, is dated 5 July 1921. Five other related patents on hand are dated up through 1933. (see Section 5.0)

All of the subject patented concepts involved recovering medium sized, manned aircraft prevelant at the time, and in all cases the aircraft were suspended at the plane of symmetry by a hook, or other device, located on top of the aircraft. In reviewing these patents one may conclude that the inventors did not reckon with the possible inconveniences attributable to centrifugal force; apparently assuming that pilot and passengers alike would not be disturbed by being abruptly snatched into a near-vertical bank at 1.5 to 3 g and being whirled around for what might have seemed like an interminable interval.

Perhaps the most significant of the available patents for the rotary concept insofar as this study is concerned is Patent No. 1,748,663, E. F. Tucker, 25 February 1930, (Figure 42). The Tucker patent appears to be a direct ancestor of a latter day concept (Figure 43) brought forth for Mini-RPVs, including the hoop used as a means of capturing an air vehicle, called the Tower Snag Recovery System. This concept was under study by NASA Ames at the time of Publication (Aviation Week, 22 January 1973). Unlike its earlier patented counterparts mentioned above, the Tower Snag involves a hook-up point off the plane of symmetry of the air vehicle. A hook/latch device installed on the RPV's wing tip is intended to engage the hoop and lock onto it. The radial arm on which the hook is mounted would then be accelerated almost instantaneously to a high rate of angular velocity. After the tangential velocity of the RPV decreases to zero, the RPV could be retrieved by lowering it to the ground by a cable/winch system as noted in Figure 43.

7.8.2 Analysis. For the RPVs of this study the radial distances, $\bar{r}$, to match given centrifugal load factors, n, shown below, are computed from

$$r = V^2/gn \tag{30}$$

4000 ft, 95°F

	120-lb 50 knots			200-lb 78 knots		
n, g	3	6	12	3	6	12
r, ft	73.92	36.96	18.48	179.88	84.44	44.97

From the above table it is evident that the radii for the lower values of n become unwieldly. Using the maximum allowable load factor of n = 12 g, a 6-foot RPV semi-span, and a 5-foot-diameter hoop, the length of the radial arms, Feb. 25, 1930. E. F. TUCKER 1,748,663

METHOD AND MEANS FOR LANDING AND LAUNCHING AIRCRAFT AND AIRCRAFT FREIGHT

Filed Sept. 20, 1927

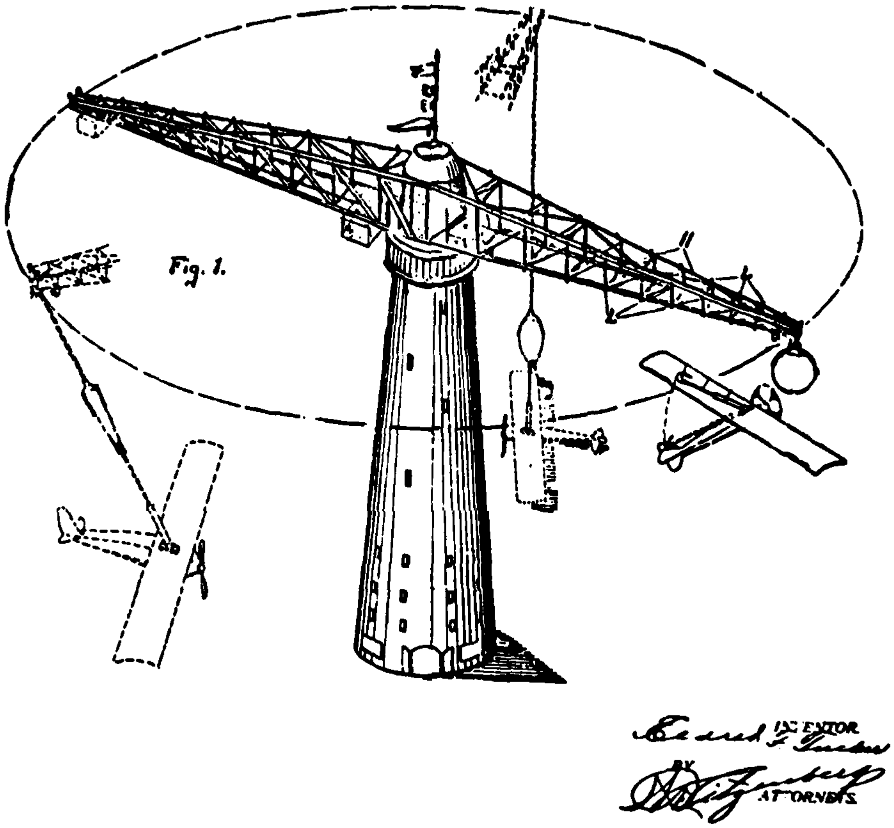


Figure 42. Early Patent, Rotary Recovery

from wing tip hook latch to the center of rotation is 7.84 feet and 33.97 feet for the 120- and the 200-pound RPV respectively, as shown in Figure 44 (a) and (b).

The arm dimensions for the smaller RPV at 12g are moderate and probably subject to further trade-off between lowering the load factors and lengthening the arm somewhat. On the other hand, the arm length for the larger RPV is probably on the unwieldly side for a rotary device.

Employing a tubular or similar type arm of a nearly 34-foot length for the 200-pound RPV class, even though it might be constructed of light-weight materials, probably would not be a practical design approach. The angular inertia of the arm can become an appreciable factor.

An alternate arrangement for the 200-pound RPV (Figure 45) would be to use an arm of reasonable length and extend a cable out to a temporary support that would drop away when the RPV engages the hoop. A winch system would be employed to reel in the cable as the RPV velocity diminishes.

Another approach for the 200-pound RPV would be to use a shorter radial arm and a pay-out cable to make up the radial distance desired. The initial configuration would be similar to that shown in Figure 44 (a). The cable would also serve to reel in the RPV as it slowed down and to lower it to the ground. However, this approach implies that initial radial load factors higher than the maximum allowable would be incurred at the instant hook-up occurs. Two cases that may be considered in this respect are:

(1) Where the pay-out cable offers zero resistance until the final dimension is reached: This means that the RPV may hit the end of the line at high velocity, and be brought to a sudden halt, possibly with destructive forces involved.

(2) Where the cable works against an energy absorber that will provide forces to resist the high centrifugal forces attributable to the shorter radius, r. An indication of the initial centrifugal load factors involved is shown in Figure 46, in which two cases are shown: one where the linear velocity becomes the tangential velocity without loss; and another, a more likely approximation, where the tangential velocity is reduced due to the exchange of momentum between the RPV and the mass of the arm, hoop, etc., that must be accelerated to the final composite tangential speed. Since the energy-absorbing payout cable does not alleviate the higher instantaneous centrifugal forces tugging at the

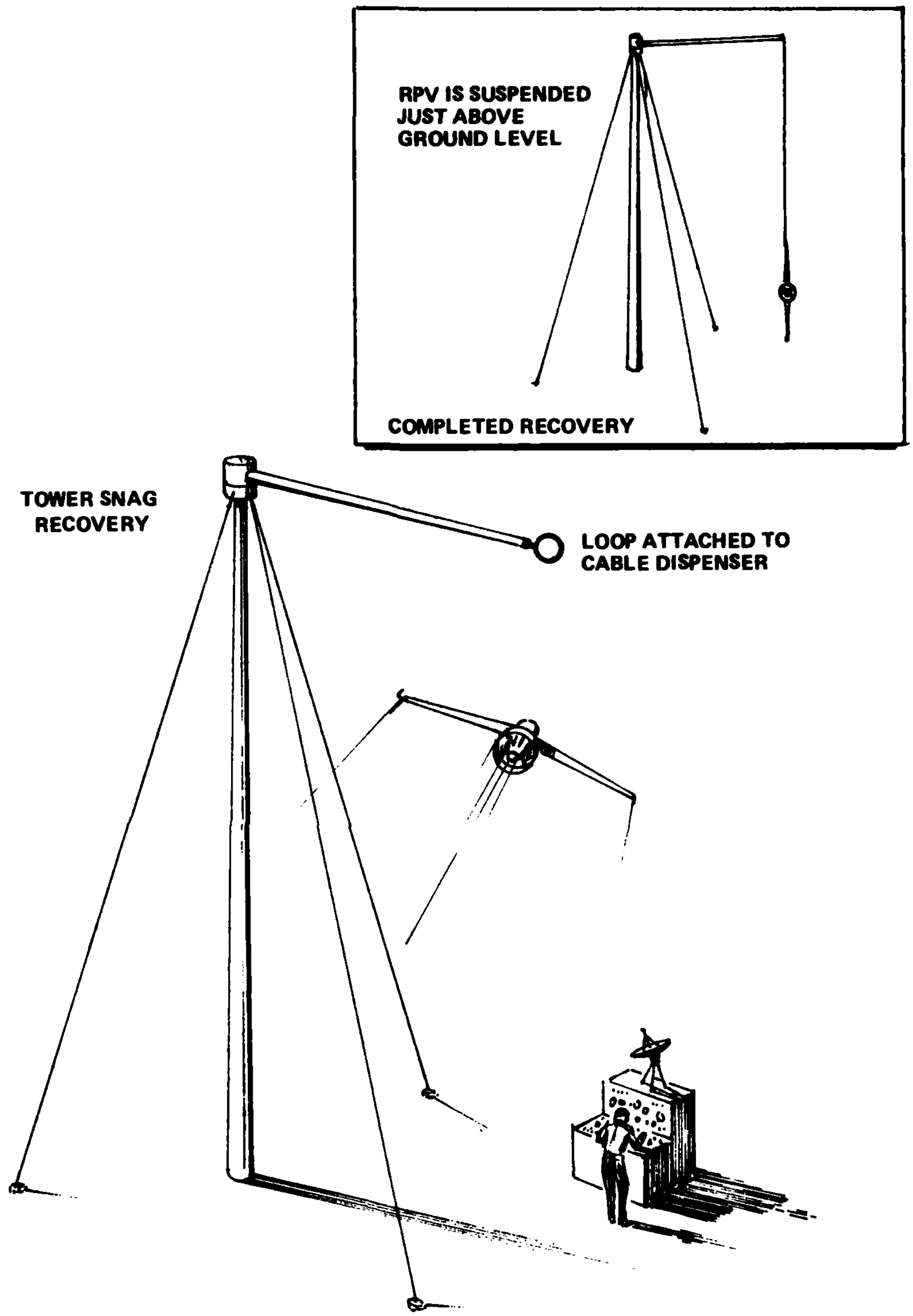


Figure 43. 1973 Version of Rotary Concept for RPVs

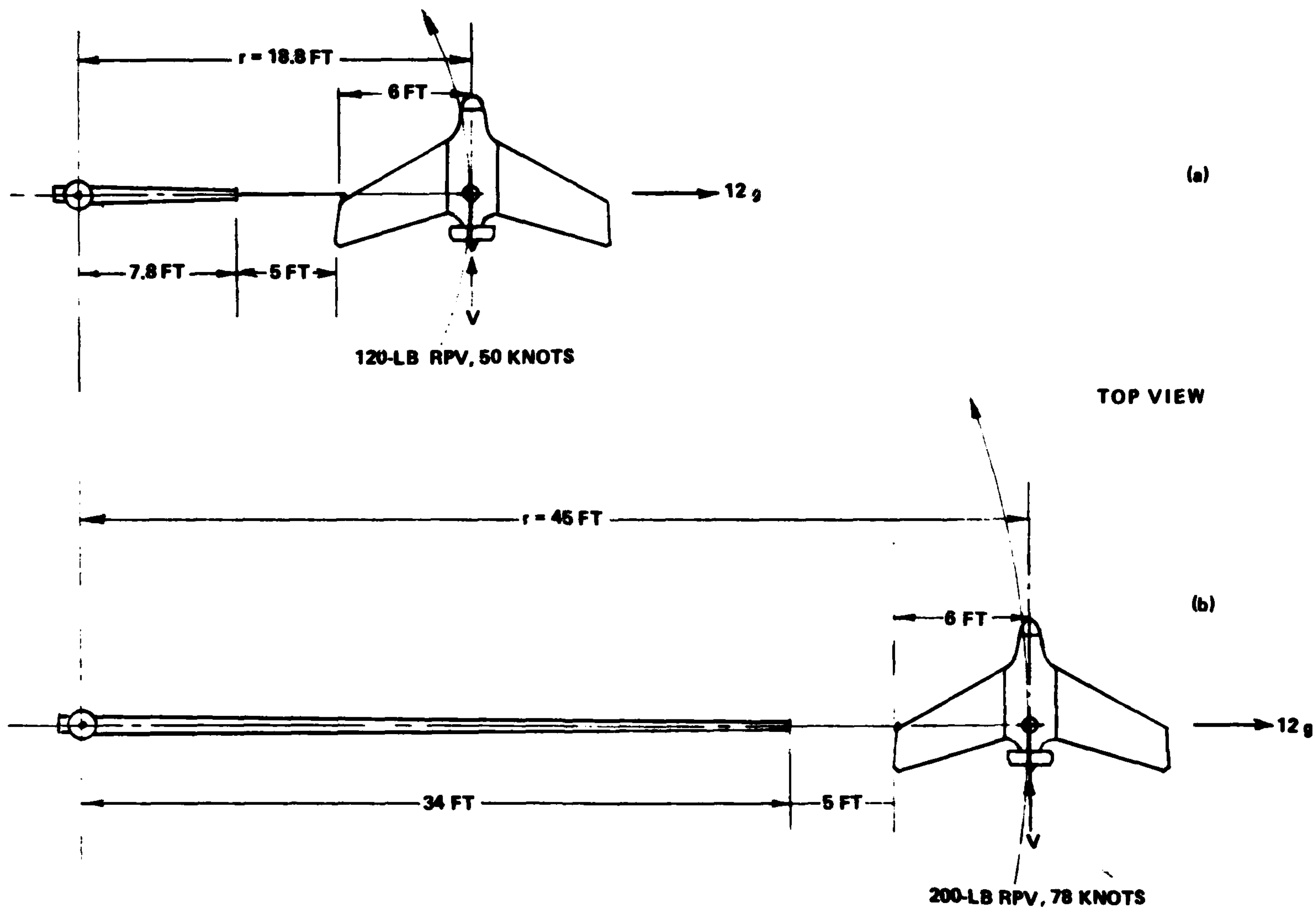


Figure 44. Rotary Radial Arm Dimensions

mass of the RPV itself, no benefit is seen for this proposition.

Target Window

Figure 47 shows typical window dimensions for about the smallest practical diameter, 5 feet, for an engagement hoop. The wing tip of the RPV could fall anywhere within the cross-hatched area and hopefully engage the rim of the hoop along the dashed line A-A. A 6-inch clearance band is assumed. At the top and bottom of the hoop there is an area within which engagement could not be effected.

Larger hoops would of course open up the window size but would accentuate some of the basic problems with the hoop system as discussed below under Conclusions.

Safety

A potential hazard in operating the rotary system most likely to happen at initial hook-up is the possibility of structural failure of the RPV or components of the rotary system mechanism. For the 200-pound class RPV traveling in about a 90-foot diameter circle, the initial few revolutions would be completed in 2 to 3 seconds. The smaller, 120-pound vehicle, traveling in about a 38-foot diameter circle would travel the circuit in 1.5 to 2 seconds. A failure under such conditions would result in an unpredictable trajectory of debris of appreciable mass, thus jeopardizing personnel and/or ground support equipment.

7.8.3 Conclusions. Overriding dynamic problems associated with the rotary recovery system are related to the eccentric manner of loading the RPV as it engages the hoop or similar engagement device and on the rotary arm mechanism while being induced to rapidly change from linear to circular motion. Since the inertia of the rotary mechanism that must suddenly accelerate from zero to a relatively high angular velocity will be appreciable, both it and the eccentrically loaded RPV will initially tend to oscillate in an erratic manner until the overwhelming centrifugal force smooths out any such perturbations. Determination of the extent and effects of such oscillations is beyond the scope of this study. Very likely both sophisticated simulation studies and experimental hardware would be required to gain a complete understanding of the problems involved.

Other problems related to the hoop that would appear to increase with hoop size involve the designers ability to

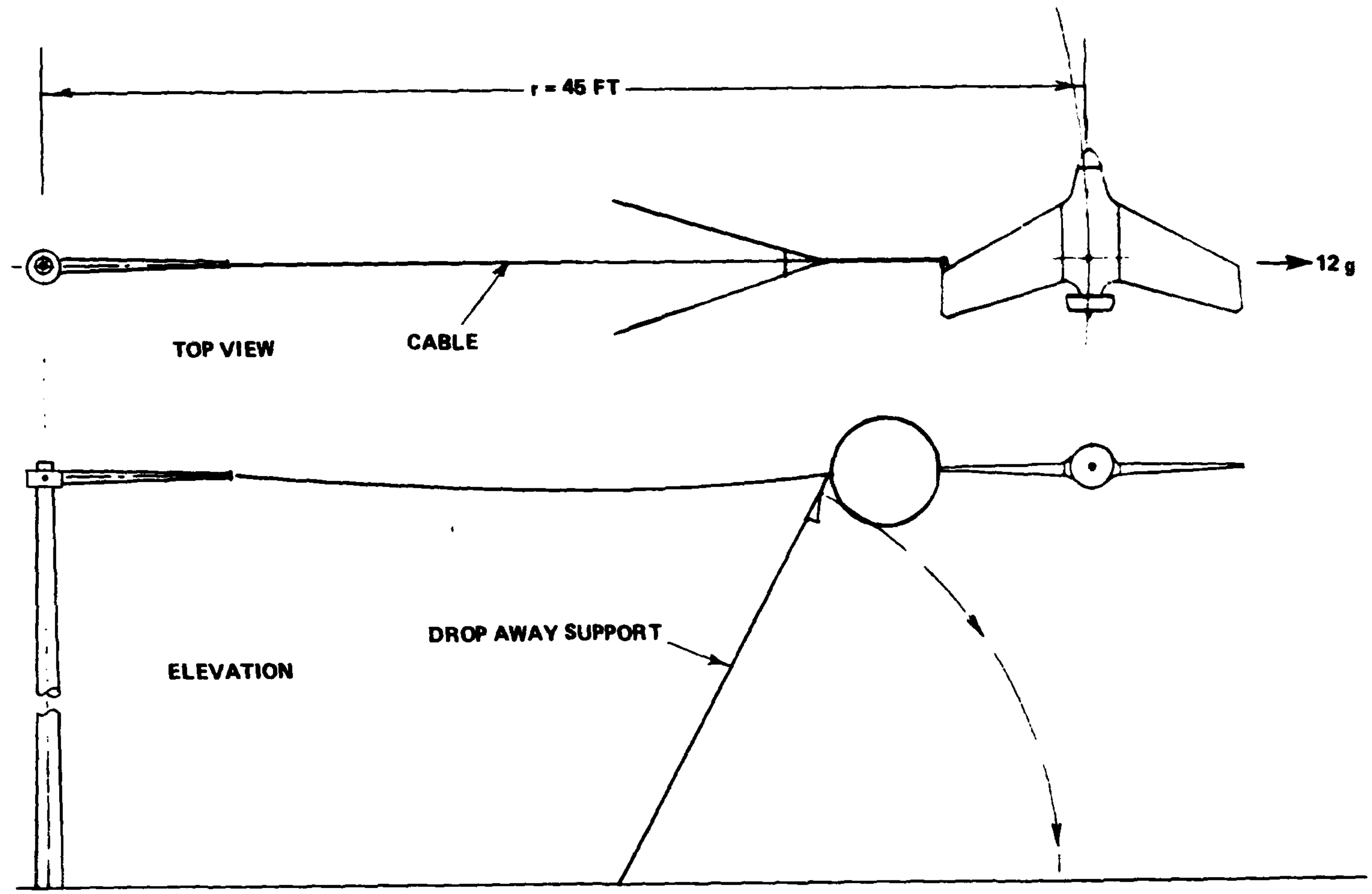


Figure 45. Rotary with Extended Arm

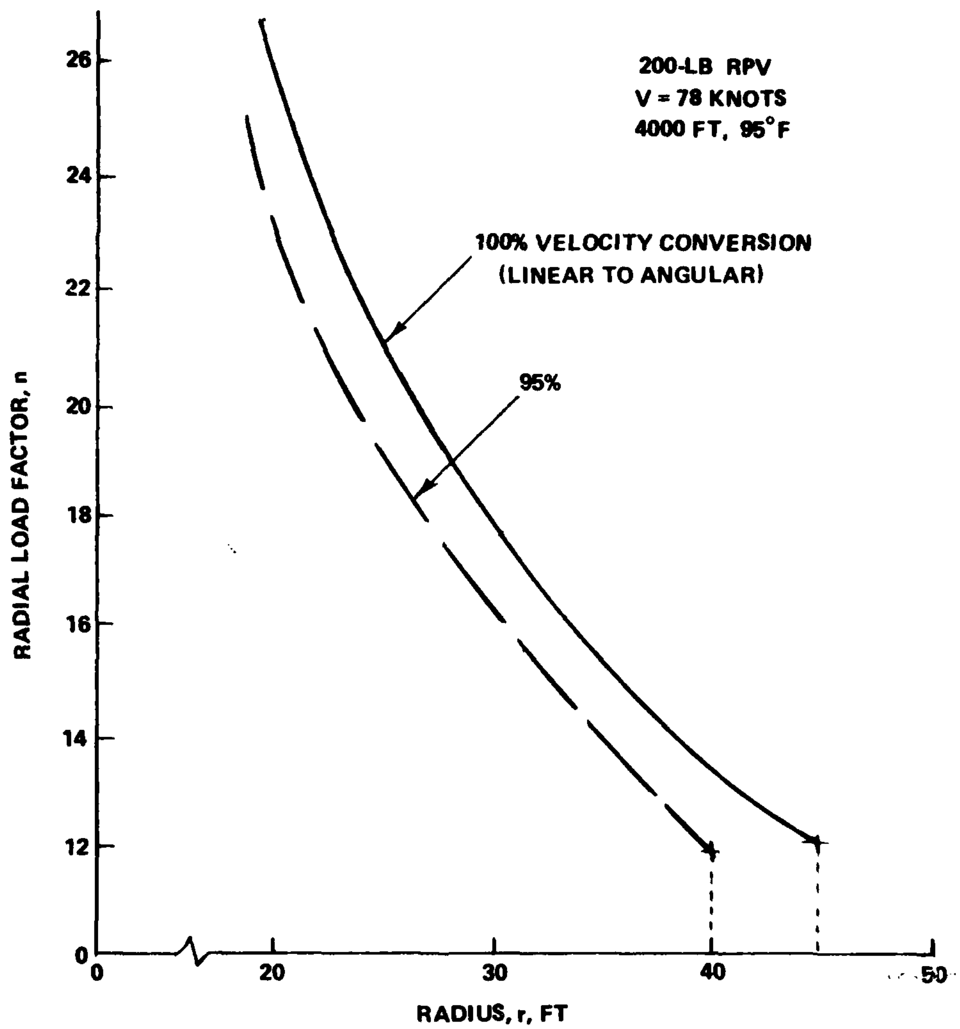
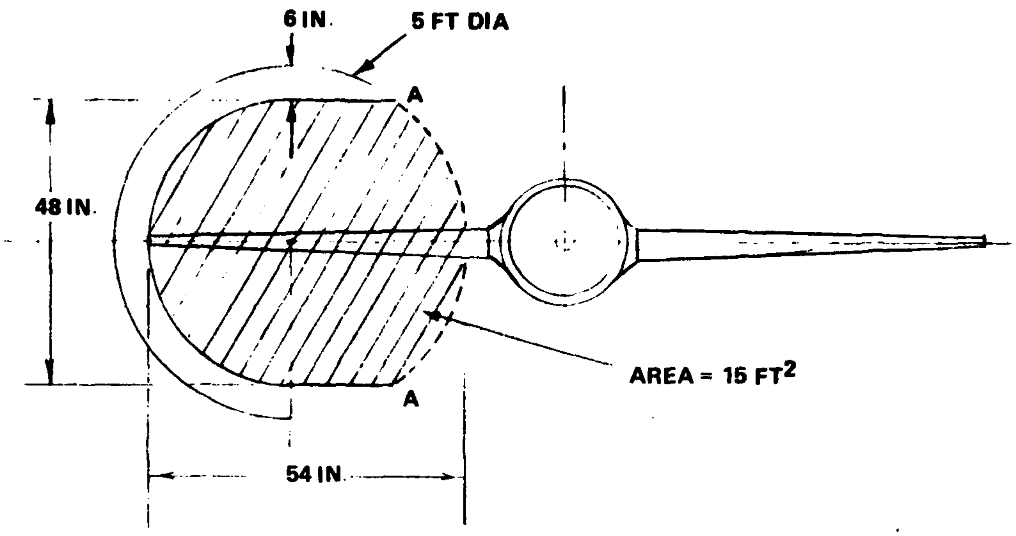
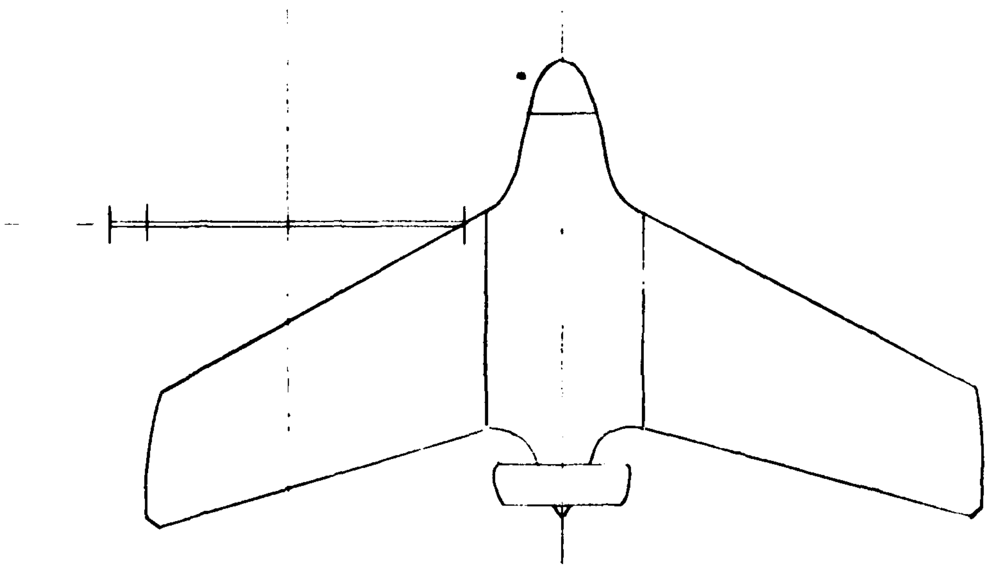


Figure 46. Radial Load Factor versus Radial Arm Length



ELEVATION



TOP VIEW

Figure 47. Rotary Target Window

preclude untoward dynamic occurrences such as the hoop bouncing away, thus missing a hook-up, when impacted by the RPV, and the tendency of the hoop to roll over or under when stuck above or below its horizontal center line. The use of advanced composite materials may offer solutions to constructing light weight, resilient hoops with suitable dynamic properties and high tensile strength.

The rotary concept has favorable qualities in some aspects such as relatively small airborne weight. A small window, the possibility of dynamic problems leading to a low score on recovery damage and reliability, and the apparent hazards noted above are the major operational factors weighing against the rotary concept. However, the concept has potentially favorable qualities related to mobility in that only one M-135 truck might suffice.

7.9 Parachute, Concept II-4

7.9.1 Introduction. The parachute in the role of above-surface recovery techniques was accepted as a satisfactory operational system for RPV recovery several years ago in the form of MARS (Mid Air Retrieval System).

In this subsection, MARS and three other concepts in various states of being are discussed. The subject study concepts are:

- 7.9.2 MARS, Concept IIA
- 7.9.3 Winch-Down, Concept II-B
- 7.9.4 Deceleration Chute Plus I.P., Concept II-C
- 7.9.5 In-Flight Hook-up, Concept II-D

7.9.2 MARS, Concept II-4A

a. General

The MARS recovery concept illustrated in Figure 48 shows a complete sequence of events for an RPV much larger than the Mini-RPVs of this study. Operational versions of the MARS have been used to recover RPVs at weights of 1400 pounds (BQM-34A) to about 3500 pounds (AQM-91A).

The system shown in Figure 48 employs a total of four

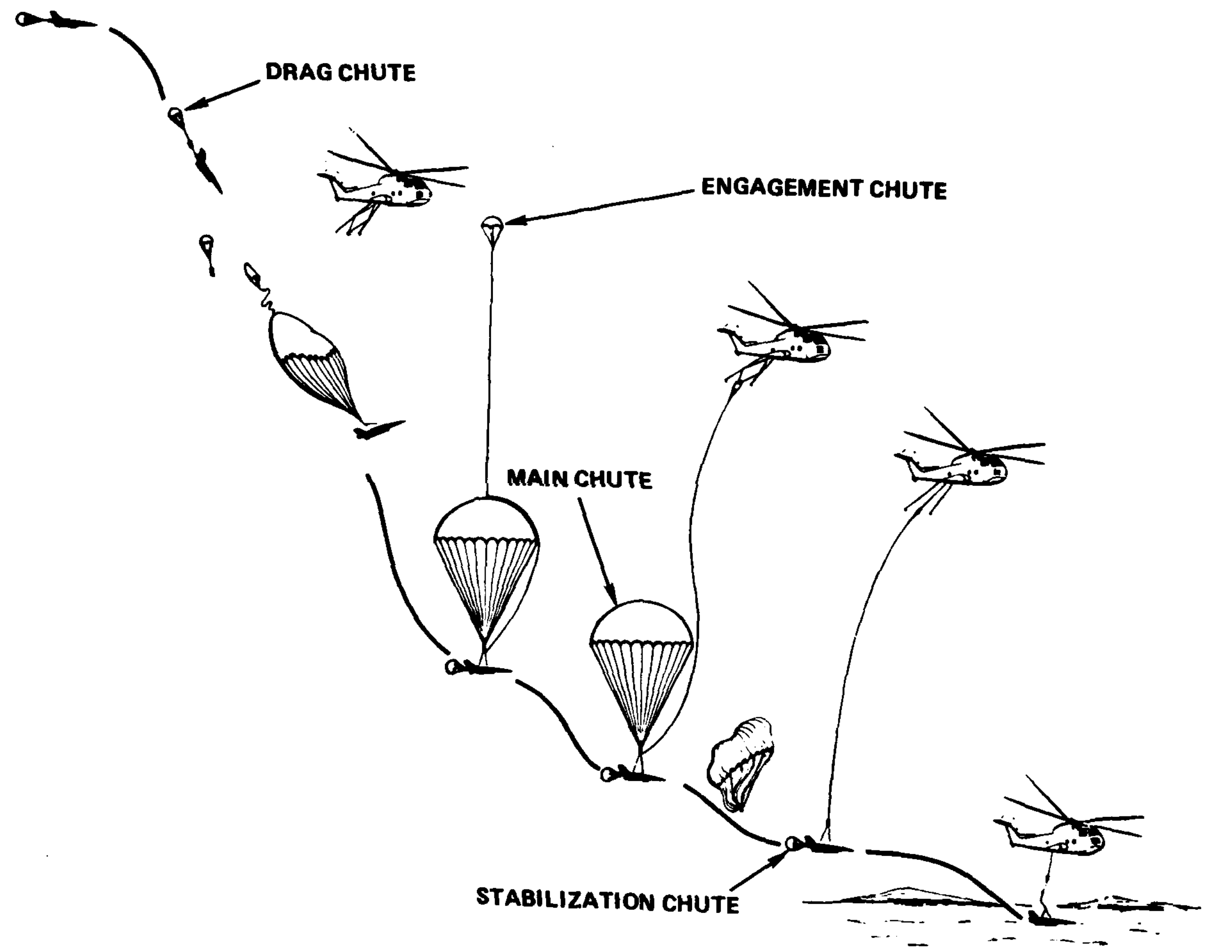


Figure 48. MARS Recovery Concept

parachutes: a drag chute, an engagement chute, main chute, and a stabilization chute. The drag chute serves a dual purpose in that it slows down the RPV and after an interval of time it extracts a can containing the engagement chute and the main chute. The engagement chute is then snagged by a helicopter with special trailing booms deployed. The load line attached to the helicopter is then released from the apex of the main chute. After a timed interval the main chute is jettisoned. The RPV is then reeled up to within a few feet of the helicopter and is towed back to the recovery area.

Carefully kept records of over 3000 MARS recovery operations show an overall RPV survivability factor of 0.94.

In the system shown in Figure 48, the chutes released during the recovery sequence (drag and main chutes) would not necessarily be expended where the operation takes place in friendly territory. The engagement chute is of course damaged each time.

The MARS system could undoubtedly be simplified for the recovery of Mini-RPVs by eliminating the drag chute and perhaps the stabilization chute. However, the main chute would probably still be jettisoned because of the potential hazards created by the chute in the final phase of lowering the RPV to the ground. Because the Mini-RPV recovery scenario includes hostile action, the main chute would most probably be declared expendable.

b. Conclusions

With the technical background now available, the MARS system could undoubtedly be adapted as a Mini-RPV recovery scheme at moderate and reasonably predictable development cost and time. However, the MARS concept has serious disadvantages with respect to the intended U.S. Army tactical employment of Mini-RPVs.

A number of helicopters would have to be modified for the MARS operation and the helicopters would have to be dedicated, or readily available, to the several Mini-RPV sections in the field. Also, the MARS recovery operation would create a signature detectable only not by visual means, but probably by all other forms of sensors, thus exposing the helicopter crew and equipment to hostile action.

The above stated disadvantages for the MARS concept appear sufficient to preclude further study of the concept for the purposes of this report.

7.9.3 Chute Winch-Down, Concept II-4B

a. General

The chute winch-down recovery concept, as shown in Figure 49 would capture a chute-borne RPV by means of a trailing cable, and then winch it down to a resilient platform or other devices designed to absorb energy. The principal feature of this concept would be the capability of bringing the RPV to a predetermined fixed point in the recovery area in a controlled manner (Reference 28).

In essence the system would consist of two stanchions, a length of lightweight cable, and a platform containing a winch and an impact energy-absorbing device. The stanchions, placed about 25 feet apart, would support a loop on the end of the cable. The stanchions should be made as high as possible so that the RPV would not have to descend after crossing the 15 meter obstacle at the edge of the recovery area.

With an extendable hook deployed, the RPV would pick up the cable loop and go into a full-power pull-up maneuver until its speed reduces to slightly higher than stall speed at which point the chute is deployed. Whether automatically or manually operated, the reel will have to take up the slack in the cable by the time the chute is in the stabilized (or near stabilized) mode of descent in order to reel the RPV down to the touch-down point.

b. Analysis

Recovery Trajectory

Computerized pull-up trajectory studies were made for the 120-pound class RPV for entry speeds of 70 and 90 knots at the 4000 ft, 95°F atmospheric condition. Results of the studies are summarized in Figure 50 for a

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28. Fogel, L. J., SKETCHES OF PARACHUTE WINCH-DOWN RECOVERY CONCEPT, Decision Science, Inc., San Diego, Ca., September 1975..

near optimum 40-degree climb angle entered with a pitch rate of 25 degrees/second. The trajectories after chute deployment, indicated by dashed lines, are estimated from the earlier work discussed in subsection 7.2.2.

The maximum energy height, h_e, is indicated in the figure for reference purposes, and accumulated time intervals are shown.

The situations shown are ideal, no-wind cases with the truck-mounted winch-down device located directly under the descending chute. Also, the stanchions have been shown to be about 50 feet high and are placed 100 feet in from the edge of the recovery area. Shortening the height of the stanchions means moving the recovery ground vehicle closer to the center of the recovery area, thus moving the whole operation downfield.

The total time from chute command to touchdown, based on an untethered chute rate of descent of 20 feet/second plus a delta of 2 feet/second to keep the cable taut, is relatively small as noted on Figure 50. This suggests that a higher speed pull-up (90 knots) would be preferable to give the winch operator more time to get organized.

The initial length of cable for the 90-knot entry speed case would be about 580 feet. At the point where the chute is in the stabilized descent mode the cable length is about 200 feet. Thus, some 380 feet of cable would have to be reeled in within about 6 seconds, at an average rate of 63.3 feet/second or about 1200 RPM for a 1-foot diameter reel. The last 200 feet would be reeled in at a rate equivalent to about 22 feet/second - if the RPV is essentially overhead.

A wind condition would, of course, require good information and suitable corrective procedures for placing the stanchions and winch-down recovery vehicle for satisfactory recovery operations. Where the wind is not properly accounted for, or abruptly changes, the RPV chute may have to be winched down with the line at considerable angular displacement from the vertical. Such situations would, of course, require higher winch speeds to keep the chute lifting enough to support the weight of the RPV.

<u>Target Window</u>

The target window at the cable pick-up point for the winch-down concept would be constrained in height by the

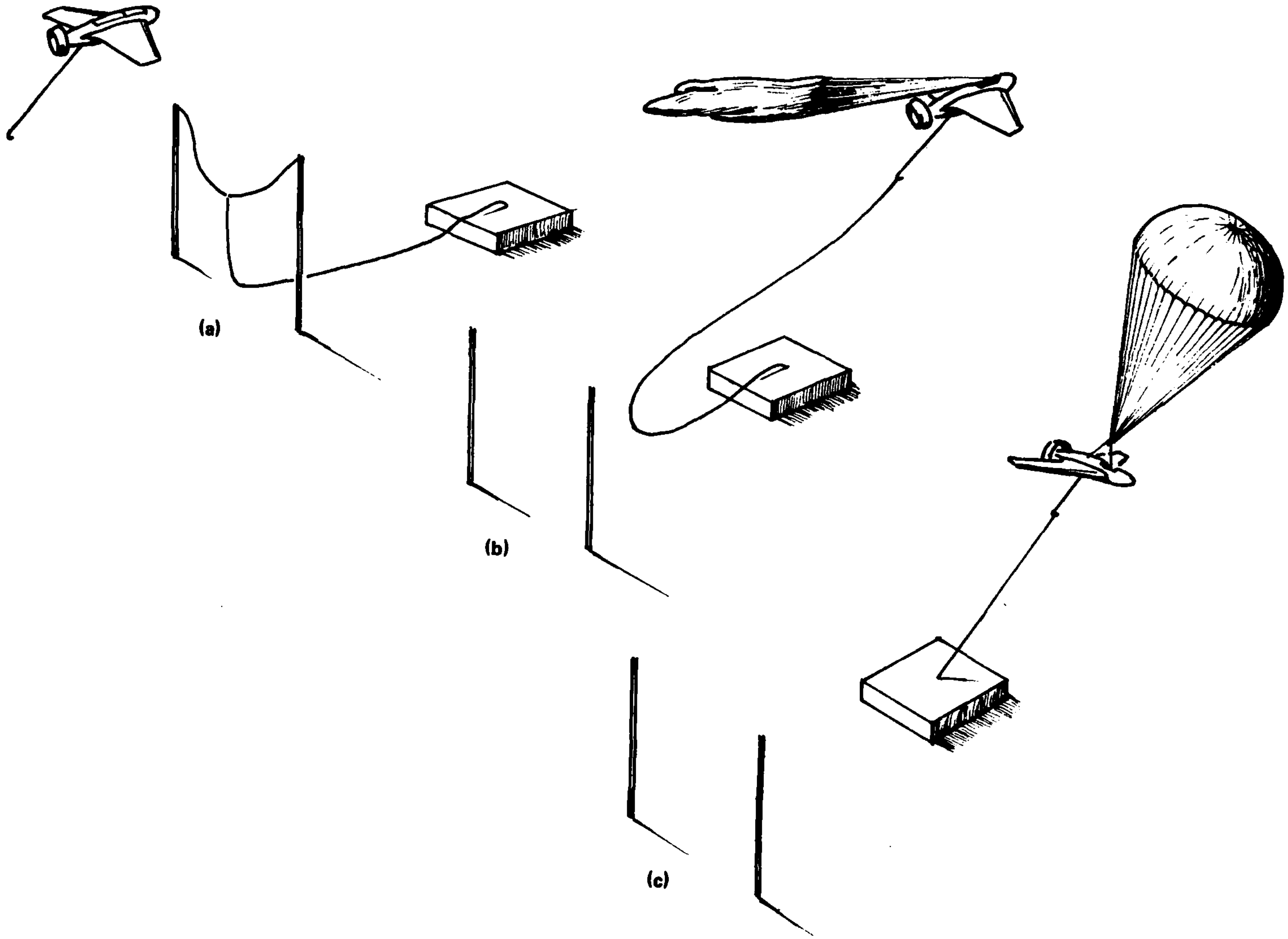


Figure 49. Chute Winch-Down Recovery Concept

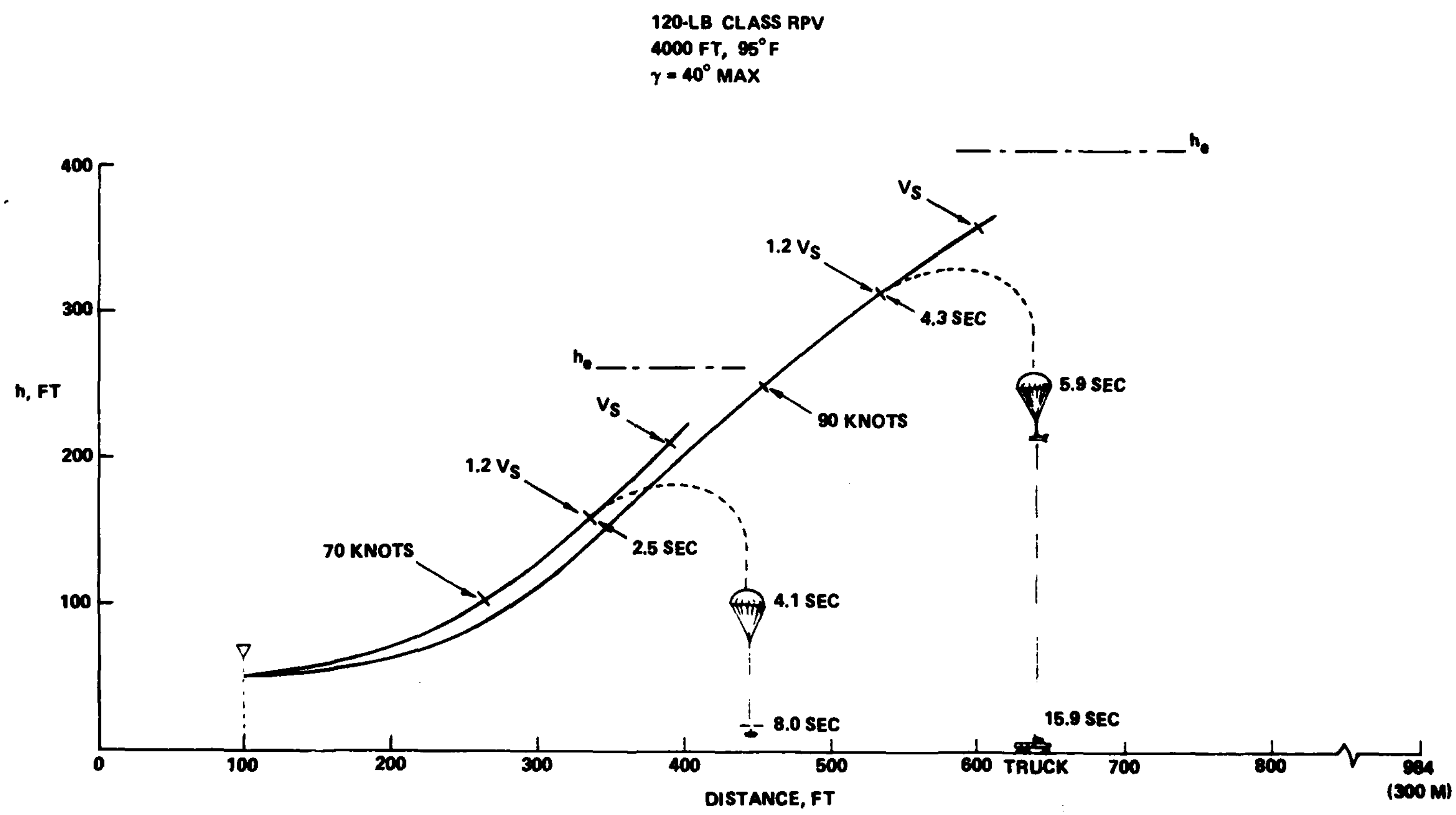


Figure 50. Pull-Up Trajectories, Winch-Down Recovery

length of its deployable hook, and in width by the distance between the stanchions. An extendable hook with a projected vertical height of 6 feet and a usable lateral distance of 15 feet for cable pickup is assumed for stanchions 35 feet apart. It will be noted that the width allowance is estimated to be greater than for the arresting wire types of subsection 7.12 because of less stringent dynamic loading conditions.

Wind Effects

With the RPV flying into the wind for the recovery operation, the recovery device would have to be placed closer to the entering edge of the recovery area to allow for the chute-supported RPV to drift back. In fact, the recovery device would have to be moved far enough back that the RPV would be upwind by an appreciable distance when the cable reel was actuated so that the RPV would not drift downwind of the truck at a steep angle as the final length of cable was reeled in.

Conclusions

The chute winch-down concept would have good wave-off, or missed hook-up performance since the RPV would be relatively high and at the edge of the recovery area at the time the recovery operation was aborted.

The visual exposure of the chute would be a few seconds longer than that for the surface impact chute concept and the signature would be enhanced by its being initially at an altitude of 300 to 400 feet. The weight of the airborne equipment (tail-hook, 500 plus feet of line, and the parachute) would probably be greater than desired.

Probably the most questionable technical aspect of the winch-down concept at this time is the effects of wind on the recovery system while the chute is being reeled in. Extensive analysis would be required to establish envelopes for safe operating conditions.

7.9.4 Deceleration Chute Plus Impact Platform, Concept II-4C

a. General

The Deceleration Chute plus Impact Platform recovery concept (Figure 51) would employ a drag chute to retard the motion of a low-flying RPV such that it would drop on an impact platform capable of absorbing the remaining vertical and horizontal energy components.

The platform could be comprised of resilient tapes, an air bag, crushable material, etc.

b. Analysis

Trajectory Data

Three arbitrary chute sizes, 14.7, 9.8, and 7.4 feet giving stabilized descent velocities of 39, 53 and 60 feet/second, respectively, are investigated. Basic trajectory data as derived from a computerized analysis are shown in Figure 52. Figure 53 plots flight path angle against time, and Figure 54 shows a cross plot of distance and velocity in terms of time.

Two recovery sequences are investigated. Making use of the trajectory data noted above, the sequences are: (1) where Mini-RPV impacts in level attitude and (2) where the flight path velocity has reached its final (stabilized descent) value.

Only the larger, faster RPV (200 pounds, 78-knot entry speed at 4000 feet, 95°F) will be investigated in the remainder of this study because it depicts the problems in their most severe aspect. The computations are also limited to the 14.7-foot diameter chute, which produces the minimum horizontal distance and stabilized descent velocity.

For the first case, where the RPV hits in level attitude, the flight path angle would be about -10 degrees, assuming that the angle of attack of the RPV is +10 degrees. From Figure 53, it is seen that the level condition occurs at 1.5 seconds for the 14.7-foot diameter chute. All other data are read from Figure 54. A summary of results for case (1) is shown below.

Chute Dia, ft	γ Deg	t, sec	V, ft/sec	Horiz Dist, ft	Vert Dist, ft
14.7	-10	1.5	50	130	10

For Case (2), the stabilized velocity is assumed to occur at the time the nominal stabilized velocity of 39 feet/second, is reached at 't' = about 2 seconds (Figure 54). The same parameters used for Case (1) are

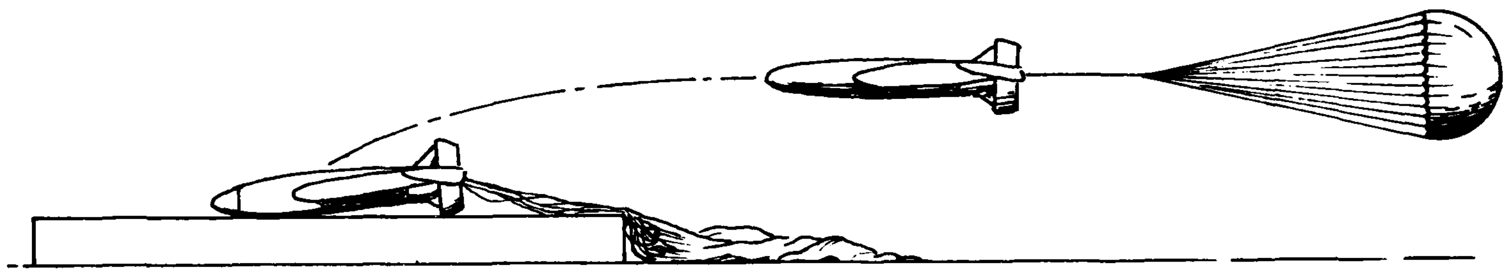


Figure 51. Deceleration Chute Plus Impact Platform Recovery Concept

tabulated below for Case (2).

Chute Dia, ft	γ Deg	t, sec	V, ft/sec	Horiz Dist, ft	Vert Dist, ft
14.7	-25	2	39	160	20

Case (1) and Case (2) results are shown schematically in Figure 55.

The velocity components at point 'B' are:

	V_h		V_v	
	ft/sec	(knots)	ft/sec	(knots)
Case (1)	49.2	(29.1)	8.7	(5.1)
Case (2)	35.4	(20.9)	16.5	(9.8)

Unless the damping of the platform were perfect in the vertical direction, bouncing and skipping of the RPV would most probably be induced.

Run-out (skidding) distances without the effects of bouncing would be approximately:

	ℓ_d, ft. $\mu = 0.3$	ℓ_d, ft. $\mu = 0.5$
Case (1)	125	75
Case (2)	65	39

Target Window

The deceleration chute plus impact platform concept would essentially have two target windows. The first would be a vertical one at Point A, Figure 55, and the second a horizontal one at the point of impact, B. Assuming that the RPV arrives at 'A' in perfect position, errors due to airspeed, engine power cut-off, chute tolerances, wind, alignment of chute and RPV (as it affects the RPV's aerodynamic characteristics), and RPV gross weight could increase the window required at B appreciably.

Now, assuming that the vertical window height at 'A' is ± 4 feet = 8 feet total, the equivalent horizontal dimension would be ± 25 feet at 'B' for Case (1), and

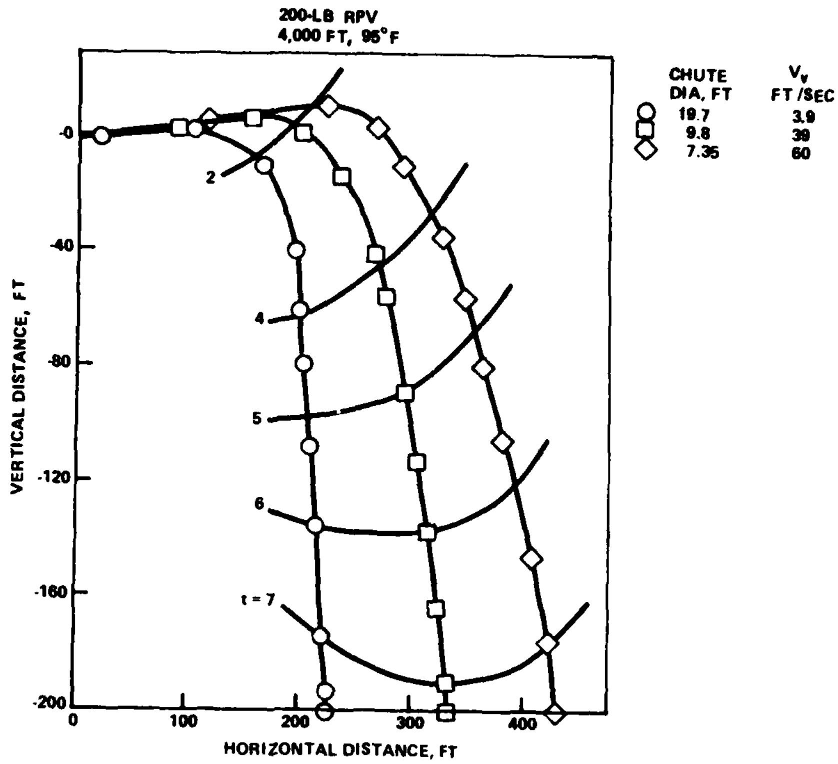


Figure 52. Basic Trajectory Data, Computer Study

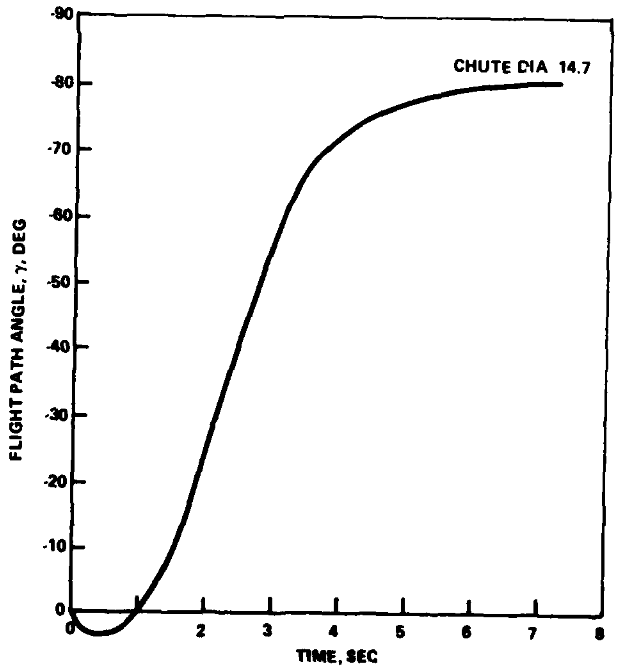


Figure 53. Flight Path Angle vs. Time

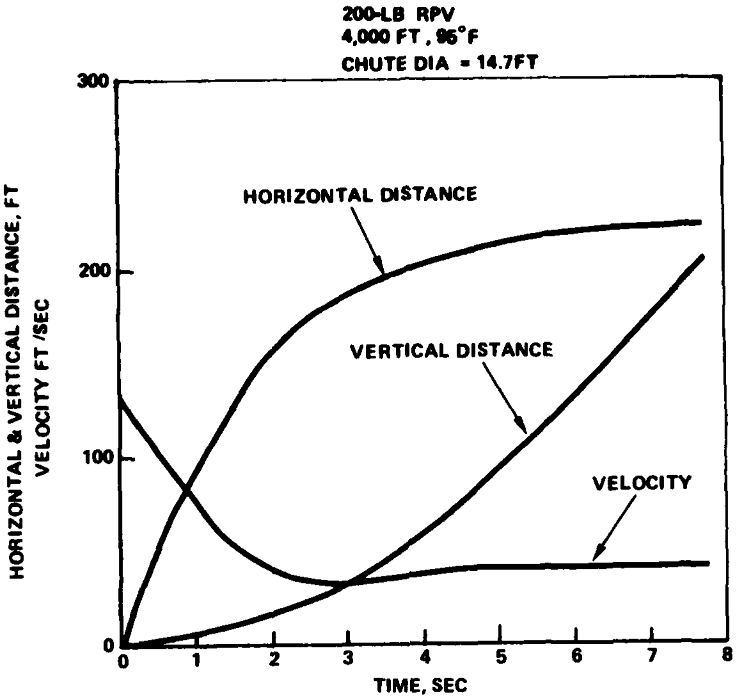


Figure 54. Trajectory Study Data Cross Plot

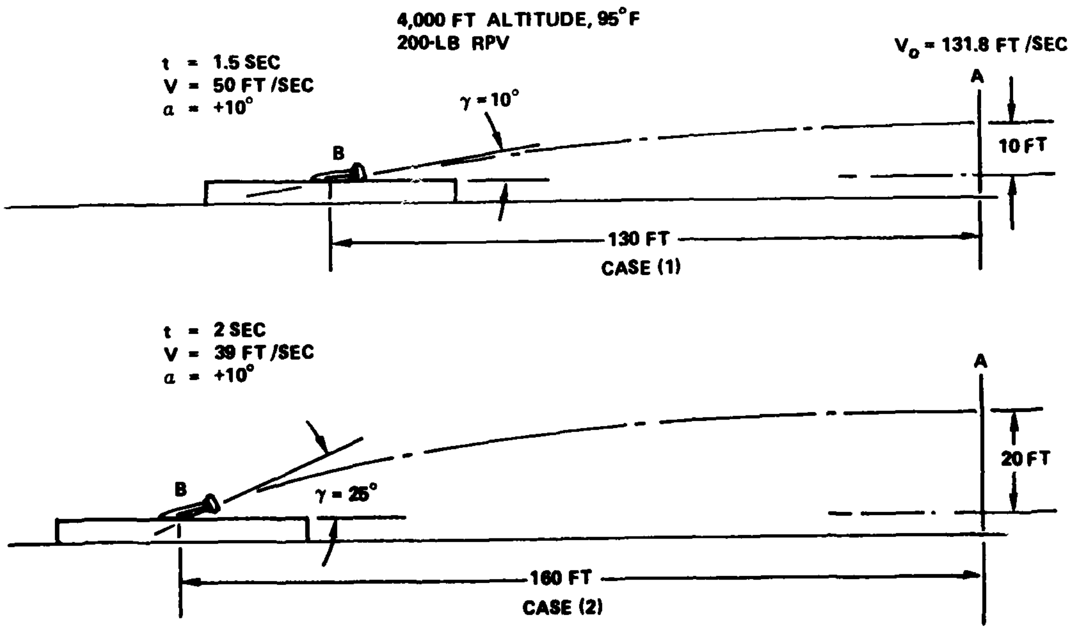


Figure 55. Recovery Sequence Schematics

about ±10 feet for Case (2). Thus, for window purposes, the size of the impact platform would have to be increased at total of about 50 feet for Case (1) and 20 feet for case (2).

The total length of the platform, with window and run-out allowances considered, could be estimated as high as 175 feet long for case (1), or as low as 59 feet for Case (2).

c. Conclusions

The deceleration chute plus impact platform concept would require reasonably low additive weight to the RPV, estimated to be not more than 4 percent of the RPV's gross weight.

The cursory analysis and target window discussions above seem to intuititively lead to the suggestion that some arrangement other than the impact platform (even if it were inclined) may be more appropriate for capturing and supplying the final means of decelerating the RPV.

In this connection, the maximum energy at Point 'B' for case (1) would be only about 14 percent of that for some of the other concepts in this study that receive the full energy of the RPV without preliminary deceleration. It is therefore possible that some form of fixed/articulated net (subsection 7.6.2) may serve better than a platform to bring the RPV to rest.

As it stands, the use of the platform appears to engender an undue number of problems related to trajectory error sources and dual target windows.

7.9.5 In-Flight Hook-Up, Concept II-4D

a. General

The in-flight hook-up concept as indicated in Figure 56 is a means of recovering an RPV by snagging a flexible fabric wing (hi-glide chute) on a transverse boom parallel to, and positioned several feet above, the ground. The RPV/chute combination would probably be flown under RPV power in a relatively level terminal approach attitude until the chute engages the projecting boom. The chute snag on aft-facing prongs attached to the projecting boom, thus causing the RPV to swing upward in an arc to dissipate its kinetic energy. The approach speeds are relatively low, depending on the wing loading chosen for the flexible wing. Nominal speeds of around 17 to 35 knots are envisioned for the Mini-RPVs of this study.

The "in-flight hook-up" terminology is used here to distinguish this concept from MARS Mid-Air Retrieval, subsection 7.9.2, in which the engagement device chases the chute; and the Transferred Chute concept, subsection 7.2.4, in which the chute is propelled from the ground to engage the RPV in flight. At least one small-scale test program, sponsored by the USAF and Navy (Figure 57) has been conducted to explore the feasibility of the in-flight hook-up concept. The model airplane shown is probably in the order of 4 to 6 percent of the RPV gross weights used in this study. However, speculation indicates that the parafoil wing loading and still-air approach speeds of the model airplane/chute combination are of the same order as those shown for the 120-pound RPV with a low wing loading described in following paragraphs. Since much of the in-flight hook-up recovery physics is solely velocity-dependent, the results of the model tests will undoubtedly be a significant contribution when made available.

The flexible fabric wing (hi-glide chute) data in the following paragraphs is representative of either the parafoil or the volplane. The performance of the parawing would probably be acceptable and the chute would be lighter. However, the rectangular shapes present much more hook-up area when they engage the projecting boom and for that reason are tentatively considered to be the most likely candidates.

b. Analysis

Hi-Glide Configurations

The hi-glide chute data below is based on a nominal L/D = 2.75 representative of the parafoil or volplane including the RPV payload.

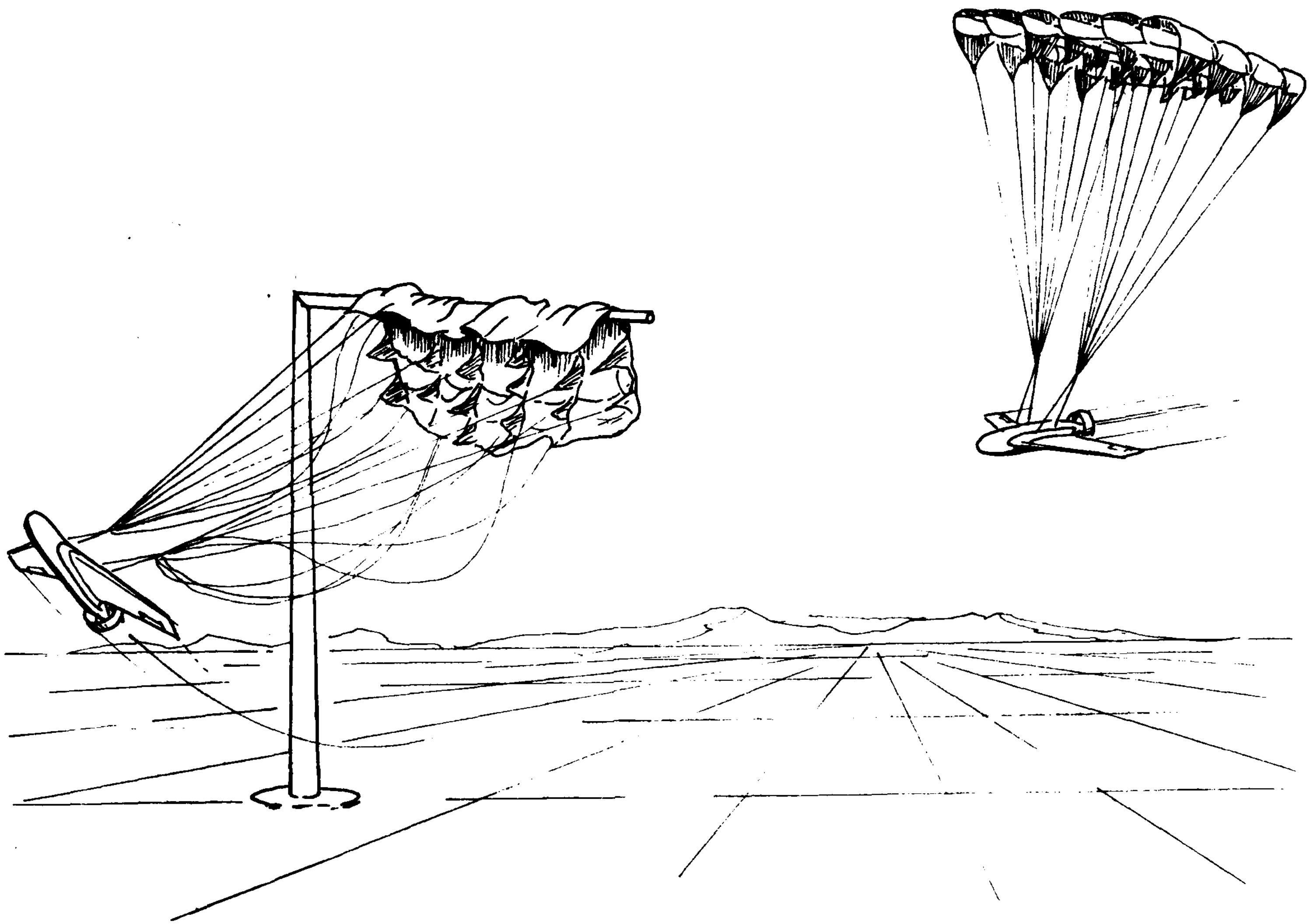


Figure 56. In-Flight Hook-up Concept

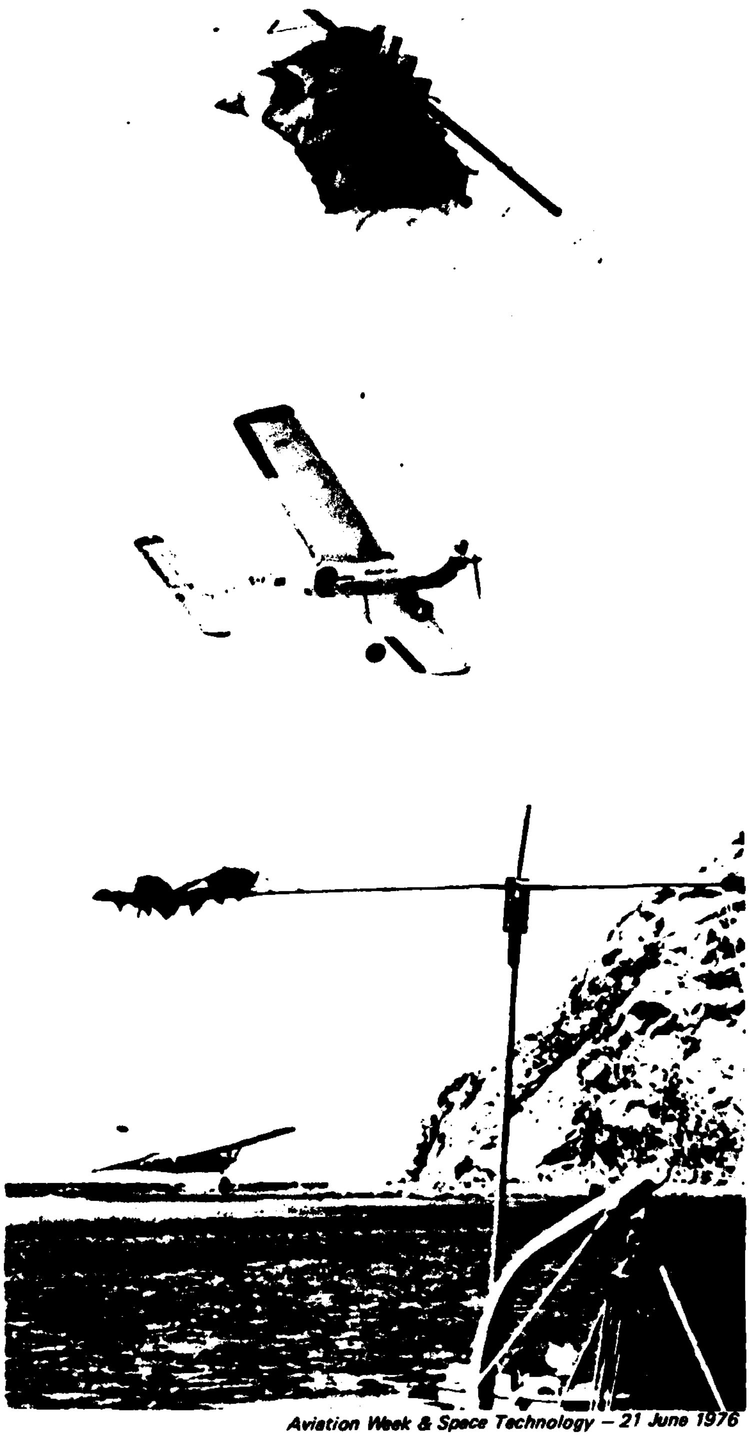


Figure 57. Parafoil/Model Airplane Recovery Tests

The analysis is based on selected vertical velocities, V_v of 10, 15, and 20 feet/second The resulting horizontal, vertical, and total speeds are:

ft/sec

V_v	V_h	V
10	27.5	29.27
15	41.25	43.9
20	55.0	58.83

The wing loading is based on a $C_L = 0.56$:

$$W/S = \frac{\rho C_L V^2}{2 \cos\gamma} \tag{31}$$

with L/D constant, γ constant, and C_L constant; therefore W/S is proportional to V^2.

The hi-glide chute areas and dimensions are computed for the 120- and 200-pound RPVs.

AR = 2.0

	120-lb RPV					200-lb RPV				
V_v	W/S	S	b	c	h*	W/S	S	b	c	h*
10	.462	259.9	22.8	11.4	39.2	.462	432.9	29.4	14.7	44.1
15	1.04	115.4	15.2	7.6	22.8	1.04	192.3	19.6	9.0	29.4
20	1.85	64.9	11.4	5.7	17.1	1.85	108.2	14.7	7.4	22.1

*h = approximate height of chute suspension lines = 1.5 x b.

Thrust Required for Powered Flight

The thrust required for the flexible fabric wing/RPV combination is based on L/D = 2.75 and may be estimated from:

$$T = W/L/D \tag{32}$$

where W = gross weight of the RPV

Figure 58 shows the thrust required for the 120- and 200-pound class RPVs for level flight, $\gamma = 0$ degrees, and for descending and climbing flight paths. The required thrust levels shown are estimated to represent higher thrust/gross weight ratios for the 4000 feet, 95°F condition than are available for the presently known Mini-RPV's in the 120- to 200-pound class. The solutions to such a problem are more power or achieving higher L/D values from the flexible fabric wings, or perhaps some of both.

RPV Hook-up Swing Action

The full radius of swing, r, Figure 59 (a), is assumed to be h + 0.066h to allow for draping or sagging of the chute after it ensnarls the hook-up arm. The 6.6 percent allowance may be inadequate.

Energy heights are computed to estimate the heights to which the RPV will swing after hook-up from

$$h_e = V_h^2/2g \tag{33}$$

The peak load factor, n_z, based on centrifugal force + 1 g is assumed to occur at, or very near, the start of the up-swing.

$$n_z = (V_h^2/gr) + 1 \tag{34}$$

	120-lb RPV			200-lb RPV		
V_h	r	h	n_z	r	h	n_z
27.5	36.5	11.7	1.64	47.1	11.7	1.50
41.3	24.3	26.5	3.17	31.3	26.5	2.69
55.0	18.2	47.0	6.16	23.5	47.0	4.98

It will be noted that the energy height, h_e, is the same for either the 120- or 200-pound RPV, being a function of speed only. The load factor, n_z is slightly less for the 200-pound RPV because r is greater.

If the energy height, h_e, is appreciably greater than r, the RPV is subject to a near vertical drop-back action until it attains enough speed to create the centrifugal force required to hold the radius, r, constant. In this regard, it will be noted that the hi-glide chute based on more than about V_h = 41 feet/second has computed energy heights appreciably more than the swing radius, indicating the likelihood of a loop maneuver. The loop,

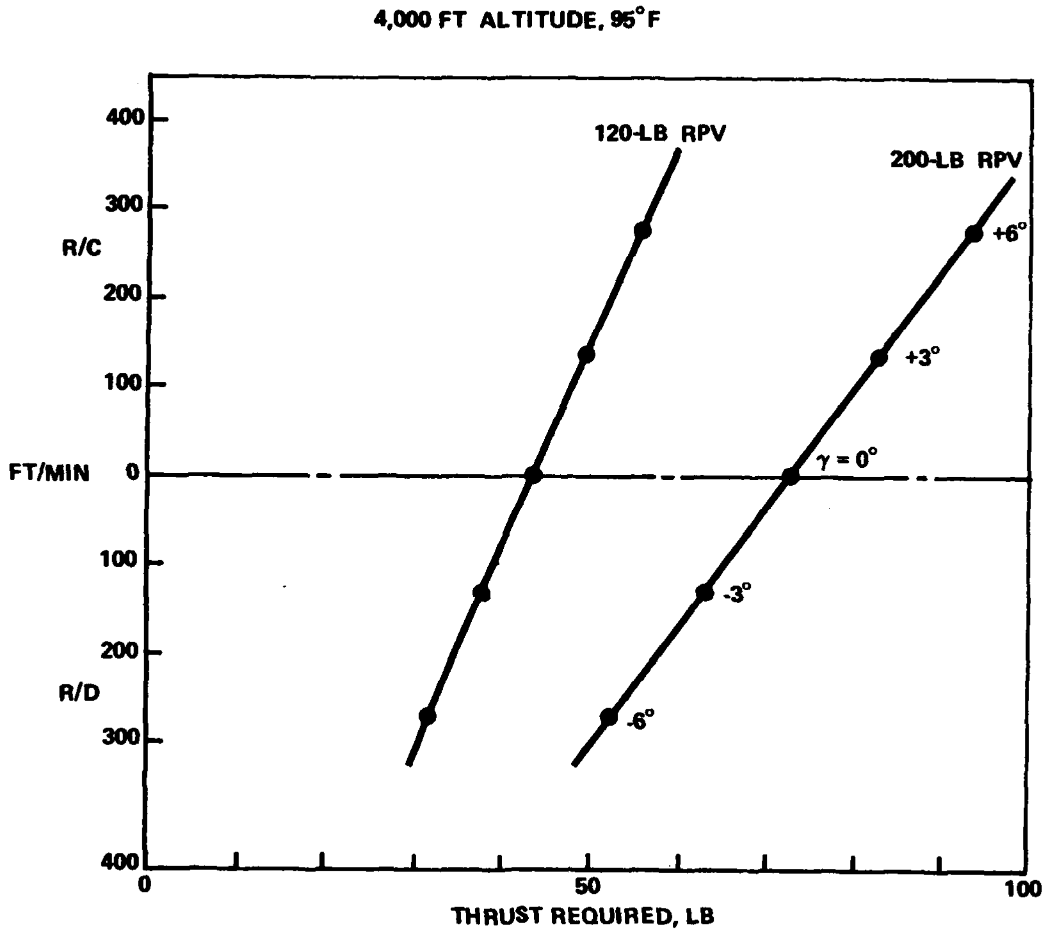


Figure 58. Thrust Required, Power Flight, Hi-Glide Chute With L/D = 2.75

per se, may not portend disaster. However, there is the possibility that the chute may slip off the engagement prong in the 3rd or 4th quadrant of the loop.

And of course an incomplete loop is probably more to be feared than a completed loop. In any event, even a well behaved swing height less than r will return a high percentage of its energy in a reverse swing. The initial over-swing problem could be alleviated by maintaining a low chute wing loading and consequently, entry speeds low enough for acceptable swing heights, h_e, or by incorporating an energy absorber such as a net to stop the RPV's upward swing.

In the above discussion of the hook-up swing action the assumption has been made that the RPV always swing on the maximum radius available; that is, that the chute must intercept the projecting boom just about at the chute's bottom surface. Actually guidance and control in the terminal phase would not necessarily be that accurate.

There is probably a vertical miss distance, h_m, (Figure 59(b)) of several feet from which the suspension lines of the chute would slide down around the boom and allow the RPV to extend the lines to the full radius. This process would involve additional shock loads on the RPV and the chute, as the chute snag the prong on the boom. The distance, h_m, would establish the vertical height of the target window. Exceeding the maximum allowable h would presumably lead to a quick wrap around of the RPV.

Figures 60 and 61, showing the relative sizes of the parafoil configuration investigated, are presented to put the chute size problem in perspective.

<u>Steering Control</u>

Some form of steering along with flight path elevation control will be needed to successfully guide the RPV/flexible fabric wing to the hook-up point (see Reference 16).

For the model airplane trials depicted in Figure 57 it is of course difficult to tell from the available photographs whether an on-board control system was installed to vary the lengths of the parafoil risers for lateral/directional control. Speculation leads to the assumption that a chute control system was not installed, leaving the only source of control moments at the model airplane's aerodynamic control surfaces.

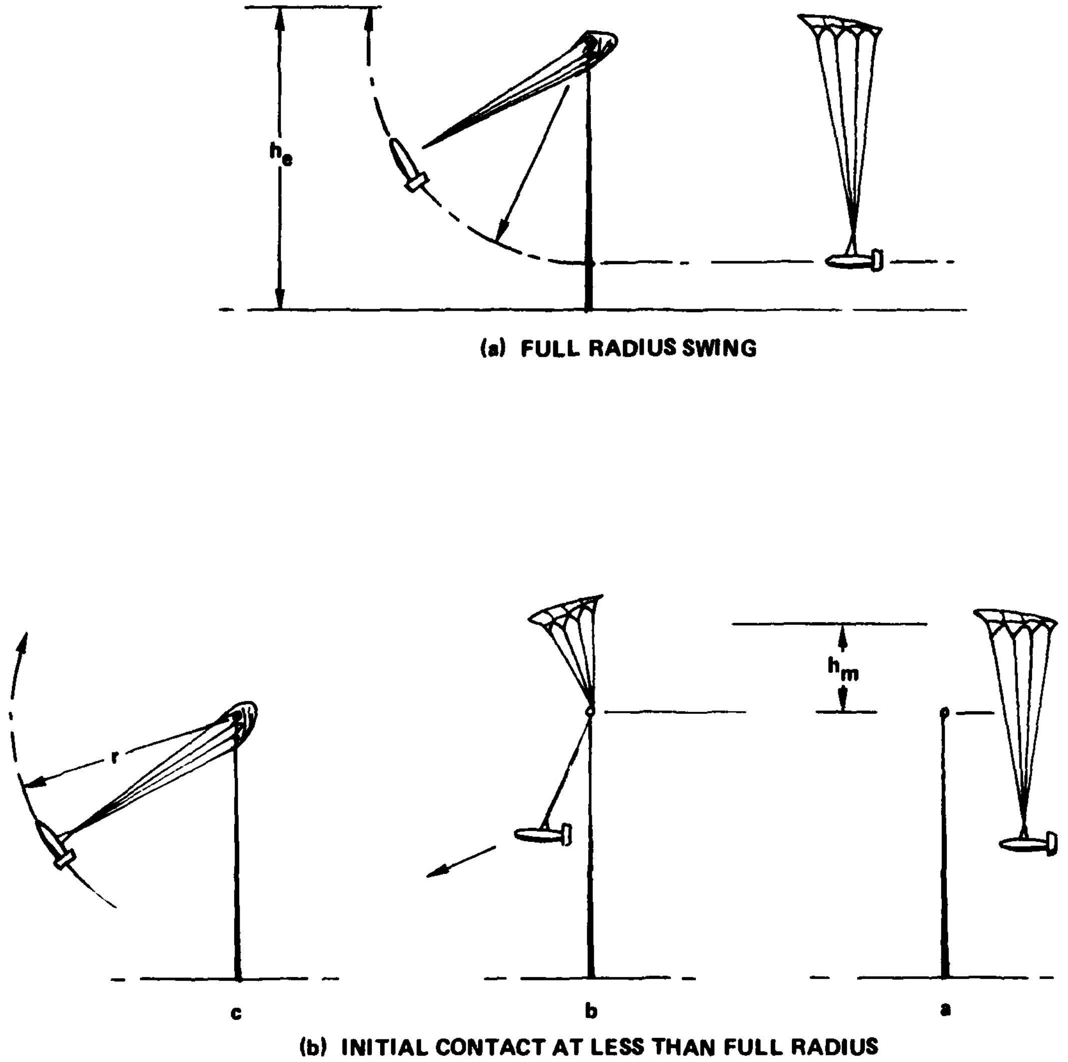


Figure 59. RPV Hook-up Swing Action

Ideally this would be the way to go. However, analysis in a depth greater than is possible within the scope of this study would be required to determine the lateral/directional control capabilities of the 120- and 200-pound RPV class vehicles in combination with a flexible fabric wing.

Recovery Approach Path

A typical approach path for the RPV to the recovery rig for the in-flight hook-up would be as shown in Figure 62. The power-off glide path, γ = 19.9 degrees plus is too steep for practical purposes and would make it very difficult to guide the RPV to the target window. Powered flight is required to bring the RPV/chute combination home. The time required to attain stabilized flight after chute deployment and perhaps to make azimuth corrections, (in view of the fact that fabric wing apparently cannot be depended upon to maintain the original heading after deployment), indicates that the chute should be deployed at a safe altitude some distance ahead of the recovery area boundary.

Target Window

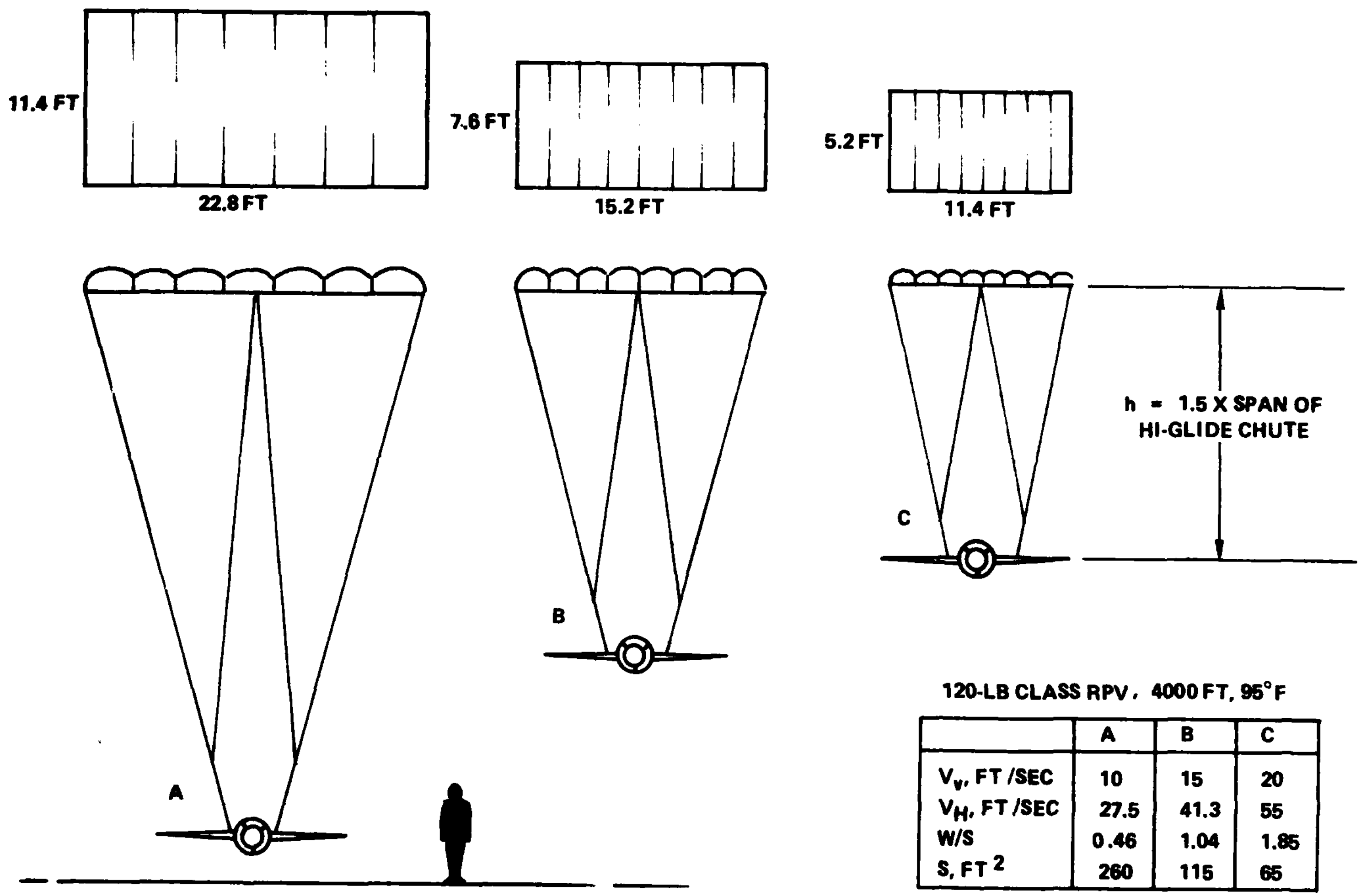
A target window size for the in-flight hook-up recovery concept could only be completely quantified after a particular hi-glide chute is selected. However, some of the qualitative considerations involved are illustrated in Figure 63.

Wind Effects

In general, into-the-wind approaches would only result in yet slower relative hook-up speeds which should still provide satisfactory engagement of the chute on the boom. However, wind effects would have to be factored into the optimization of the combined hi-glide chute/RPV vehicle characteristics, since thrust capabilities of the RPV may be affected.

c. Conclusions

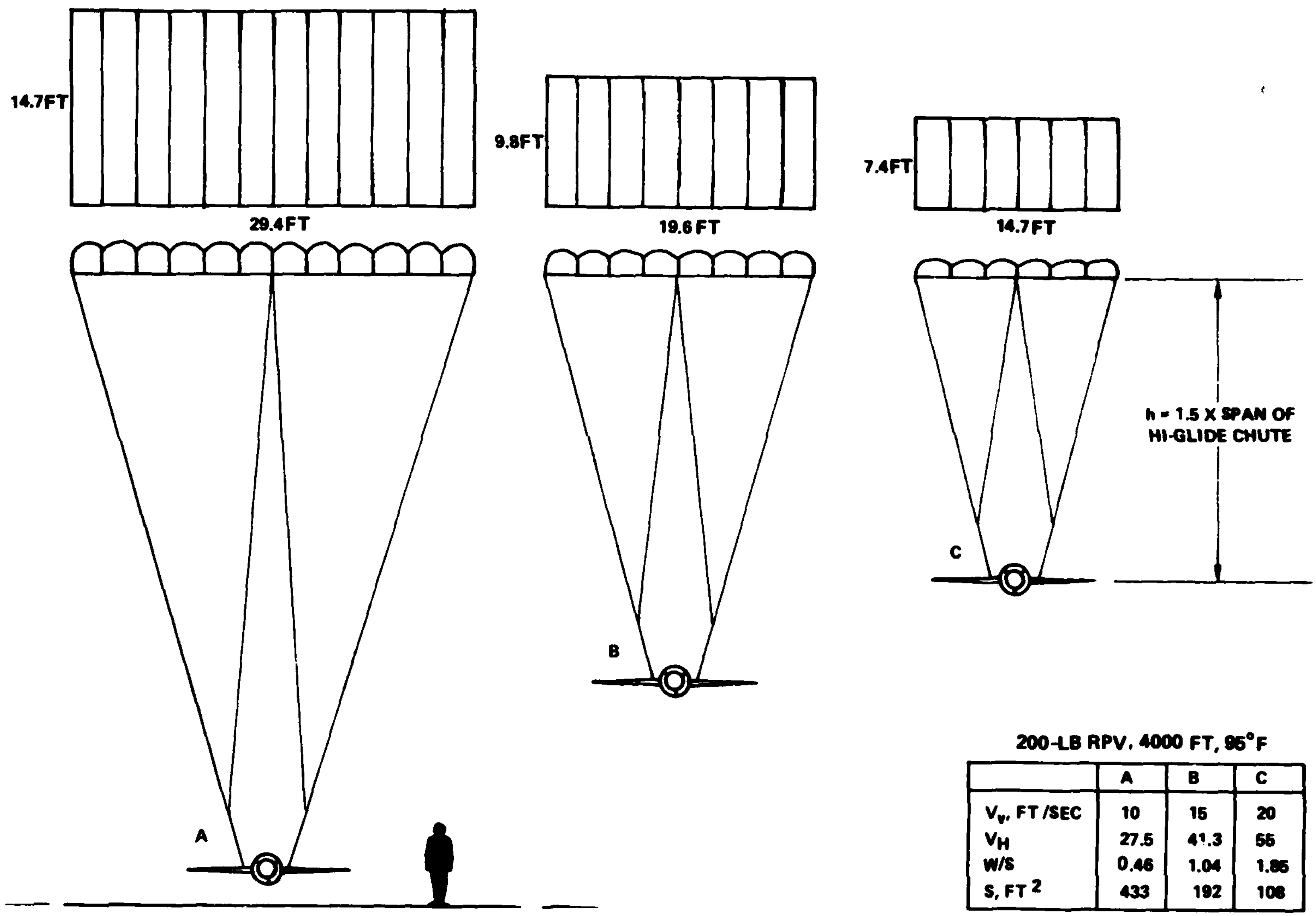
The in-flight hook-up recovery concept appears to have some measure of credibility in view of the model airplane trials noted above. And, as a result of the cursory studies above, it appears that only moderate technical problems are involved. However, in-depth analysis and flight tests of full-scale hi-glide chute/RPV hardware would be required to completely validate the concept.



120-LB CLASS RPV, 4000 FT, 95°F

	A	B	C
V_V, FT/SEC	10	15	20
V_H, FT/SEC	27.5	41.3	55
W/S	0.46	1.04	1.85
S, FT^2	260	115	65

Figure 60. Parafoil Configuration Dimensions



200-LB RPV, 4000 FT, 95°F

	A	B	C
V_V, FT/SEC	10	15	20
V_H	27.5	41.3	55
W/S	0.46	1.04	1.85
S, FT^2	433	192	108

Figure 61. Parafoil Configuration Dimensions

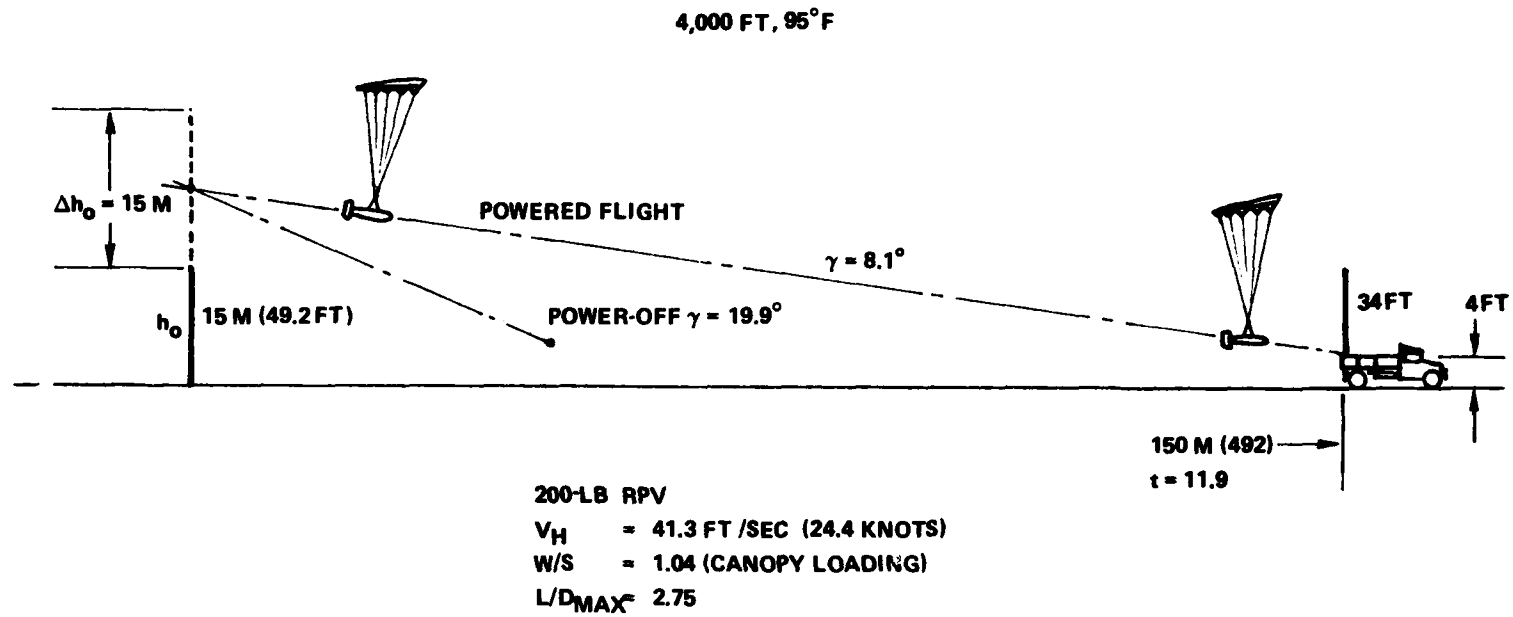
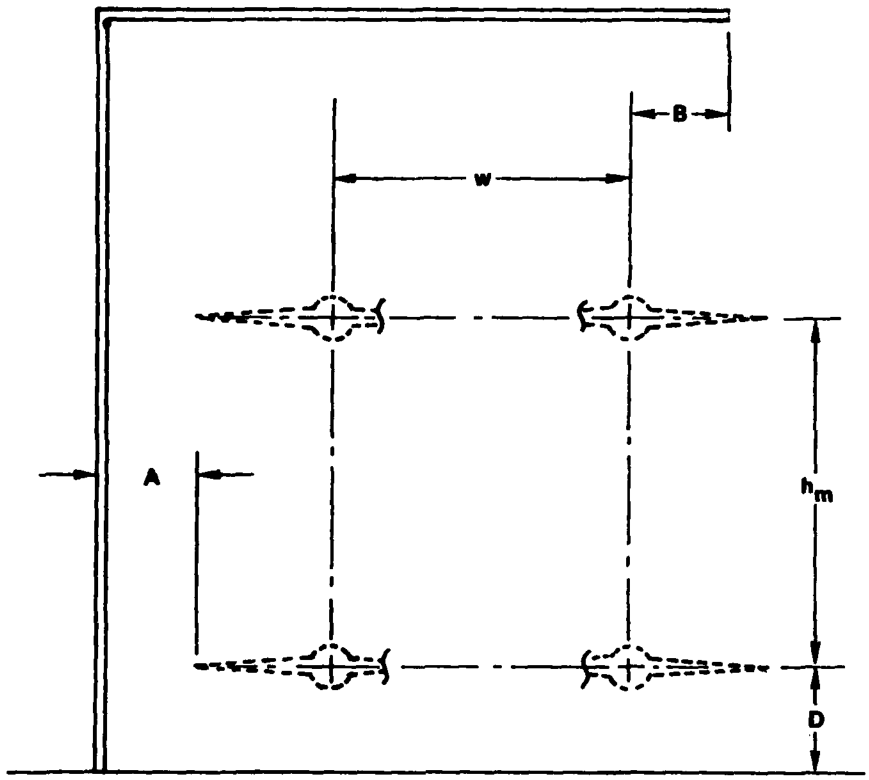


Figure 62. Typical Recovery Approach Segment



A MINIMUM TIP CLEARANCE

B MINIMUM DISTANCE TO CATCH SUFFICIENT NUMBER OF SHROUD LINES

D MINIMUM GROUND CLEARANCE DIMENSION

h_m TARGET WINDOW HEIGHT

w TARGET WINDOW WIDTH

Figure 63. Target Window Dimensional Considerations

Low approach speeds of the hi-glide chute/RPV unit are favorable where manual control take-over from the ground may be necessary. Retrieval of the RPV would be relatively easy as it comes to rest in its final position suspended above the ground.

The major development item to be considered is the airborne flight control system required to steer the vehicle. As indicated by the analysis above, the in-flight hook-up operation could require design thrust levels for the RPV that are greater than those for the free-flight regime. The weight of the airborne items (hi-glide chutes and steering control system) would probably be greater than desired. The visual signature chargeable to the hi-glide chute would last slightly longer than the chute deployment sequences noted in subsection 7.2.

The hi-glide chute may necessarily be declared an expendable item due to damage incurred during the hook-up and subsequent loads applied by the RPV as it swings through.

7.10 Aerial Track, Concept II-5A

7.10.1 General. The aerial track (or runway) recovery concept as illustrated in Figure 64 is shown as a form of traveling net with a long stroke, or deceleration distance. This type of system could be used where it is desired to keep the maximum deceleration load factors imposed on the RPV at low values, (2 g or less).

The upperside of a net, or other engagement device is attached to a trolley that travels down a cable supported at either end by cantilever arms projecting from support stanchions. The RPV is captured by the net, or otherwise engaged, and the net/RPV/trolley unit travels along the track cable. A snubber line attached to the trolley passes over a system of pulleys to an energy absorber mounted on a stanchion. At the end of the travel, a few feet from the cable support arm, the RPV could be retrieved by lowering the track cable by means of a winch.

Like the inclined ramp concept, subsection 7.7, and the rotary (Carousel), subsection 7.8, the aerial track was originated many years ago. A 1948 patent, T. M. Boyer, et al, which is called an "Arresting Unit for Aircraft Landing

System" is shown in Figure 65. Another 1948 patent, J. H. Brodie, pertaining to a "Landing and Launching Apparatus for Aircraft" involves four cable-braced towers, and an elaborate system of guy lines which employed 24 ground attachment points. The Brodie concept is perhaps better known because successful tests were conducted with it using small manned aircraft, such as the Piper L4 and Stinson L5.

Both the Boyer and the Brodie systems incorporated an engagement hook mounted on the top side of the aircraft. In the Boyer system, a wire leading to a trolley was attached with break-away ties across the short vertical arms projective below a horizontal support arm. The hook on top of the aircraft engaged the wire which would travel down the track cable on the trolley resisted by a snubber line from a hydraulic brake-type energy absorber. In the Brodie system the hook on top of the aircraft engaged a bridle made of nylon rope attached to the trolley. This system also incorporated a snubber line from a brake drum-type energy absorber.

For the Mini-RPV application a capture net with a light, flexible frame made of fiberglass or advanced composite materials is indicated in Figure 64. The net would be formed in a bag shape to retain the RPV after capture. This would require that the forward end of the net be supported by a light support line attached to the track cable. To maintain the net shape for maximum penetration of the RPV, the support line, having served its purpose, would be cut away as the trolley passed it. To provide the same target window size that appears to be needed for the other type of RPV recovery net concepts (about 35 feet wide and 18 to 20 feet high) in conjunction with the bag shape and a flexible frame, would produce a total "drop" dimension estimated at about 30 feet below the attachment point at the top of the net with the RPV in the net. The stanchion would then have to be at least 35 feet high and the horizontal support arm would project about 22 feet from the stanchion.

Another approach to the engagement net problem would be to use a ribbon type net supported only along its top edge with a lightweight horizontal tube of fiberglass or similar material. The RPV would deploy a short, extendable hook/arm angled aft on the top side of the vehicle to engage the net. As the nose of the RPV penetrated the net, the hook would engage one of the ribbons. A latch feature, built into the hook, similar to that proposed for the rotary (Carousel) concept, subsection 7.8, would lock the RPV to the ribbon.

In view of the fact that the side and bottom edges of the ribbon net would be free, the outside dimensions, especially

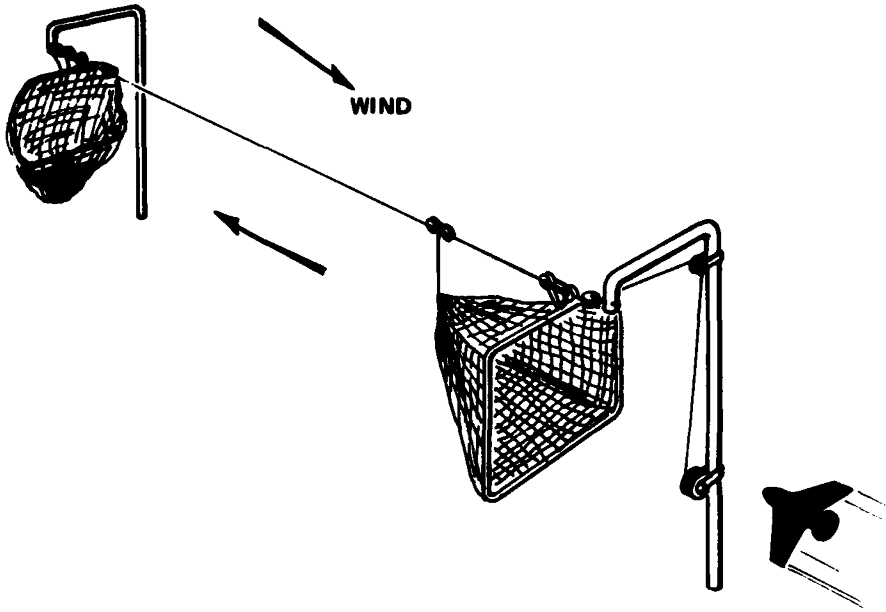


Figure 64. Aerial Track Recovery Concept

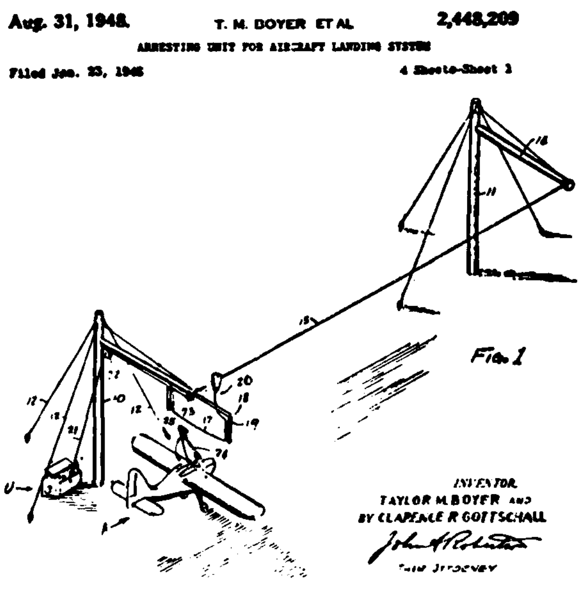


Figure 65. Patent, Aerial Track Concept

the width, of the net could be appreciably smaller than the bag type net. A hook engagement could conceivably be made close to the side and bottom edges of the net. Off-center engagements, even to the edges, would tilt the net such that the RPV hung directly below the trolley.

7.10.2 Analysis The ideal overall travel of the RPV on the aerial track cable can be estimated from

$$\ell_d = V^2/2gn \tag{35}$$

Expressed in terms of load factor, n, the distances for four arbitrarily assumed g levels are:

n,g	1.0	1.5	2.0	3.0
	ℓ_d			
120-lb RPV, 50 knots	111	74	55	37
220-lb RPV, 78 knots	270	180	135	90

The choice of a cable length would involve several factors. It appears that the aerial track system would be at its best for the lower load factors. Chosing the design load factor on the high side invites undesirable swinging oscillations of the double-hinged pendulum (trolley to top of net link, and effective link from top of net to RPV) unless the snubber line load can be programmed rather precisely throughout, including a smooth onset progression of load.

On the other hand the longer cable lengths that go with the lower load factors would require somewhat greater stanchion heights to allow for cable sag.

The cable tension loads imposed on the cantilever projecting support arms cannot be accurately determined in a cursory manner since the actual amount of sag on which the tension depends is a function of the elastic properties of the stanchion/arm structure.

However, order of magnitude figures can be obtained by making the assumption of a 135-foot cable length with the weight of the RPV, net assembly, and trolley (estimated 240 pounds) at its midpoint, a 3-foot sag would give roughly a 2700 pound tension load, and a 5-foot sag, about 1600 pounds. Of course, as the structure deflects the sag increases, and the load decreases until a stable point is reached.

Using the lower estimate of 1600 pounds, the maximum bending moment in a 22-foot support arm would be 422,400 inch-pounds. The stanchion at 35 feet in height, would be subjected to a maximum bending moment of 672,000 inch-pounds plus a torsional moment of 422,400 inch-pounds. Such numbers are indicative of fairly large member sizes, especially where elastic considerations may predominate.

The shorter cable lengths and the associated higher load factors would aggravate the pitch-up tendency of the RPV/net combination. The higher the retarding force (load factor), the higher the stabilized pitch of angle would be. Peak retarding loads above the desired average force could cause wild swing oscillations which may, in the end, do no harm if the swing arm is long enough. For the manned aircraft trials (photos illegible for printing) the distance from the trolley down to the aircraft appears to have been 20 to 25 feet, and the swing angles appear to correspond to much less than 2 g.

Target Window

With either the bag type or ribbon type nets discussed above the effective target window dimensions would be about the same as those for the capture nets of subsection 7.6.

It is interesting to note that the Brodie system with the bridle engagement device presented a very narrow target window. The compensating feature appears to have been that the pilot of the aircraft could use the track cable above and ahead of him as a directional steering fix.

Wind Effect

Assuming that the conditions of mobility are met such that the track cable is always lined up with the wind, the effects of a headwind, a lesser true speed, would be to shorten the travel of the RPV if the retarding force is set for the no-wind condition. Options are: adjusting the energy absorber for less retarding force, using the full run-out, or increasing power for the RPV to impact the engagement device at the design true speed.

7.10.3 Conclusions. The basic aerial track concept has credibility as a basic concept in that it was reduced to practice with manned aircraft about 30 years ago.

The concept, as previously noted, resembles the traveling net, but has a much longer travel distance which would inherently call for at least two land vehicles on which to mount the system.

The aerial track system could very probably meet the requirements for erecting and dismantling the system with the number of personnel allotted. The time to reposition the vehicles for a change in wind direction and put the system in ready condition would probably exceed 5 minutes, however, experience with actual hardware would be needed to make a determination. Some rather husky support members mounted on each land vehicle would be required for the track cable system.

The visual signature presented by the aerial track deployed in the field would be much the same as other concepts that require two land vehicles.

A major problem with the system is to develop the net (or wire) engagement device to provide a target window of sufficient effective size (earlier assumed to be equivalent to the traveling net), with the possibility of swiveling and pitching due to the single-point suspension of the net.

The development time and cost for an aerial track system is estimated to be moderate.

7.11 'U' Control, Concept II-6A

7.11.1 General. The 'U' Control concept proposed for RPV recovery is named for a familiar model airplane flight technique where the model is flown in circles while tethered by lines attached to its wing tips.

A description of the 'U' Control concept presented in Reference 21 is repeated here for convenience.

The 'U' Control recovery system is based upon an old and proven principle illustrated in Figure 66. When a slow flying aircraft trails a long line with a weight at its end and undertakes tight circling flight of short radius in the proper manner, the weighted end of the cable will assume a

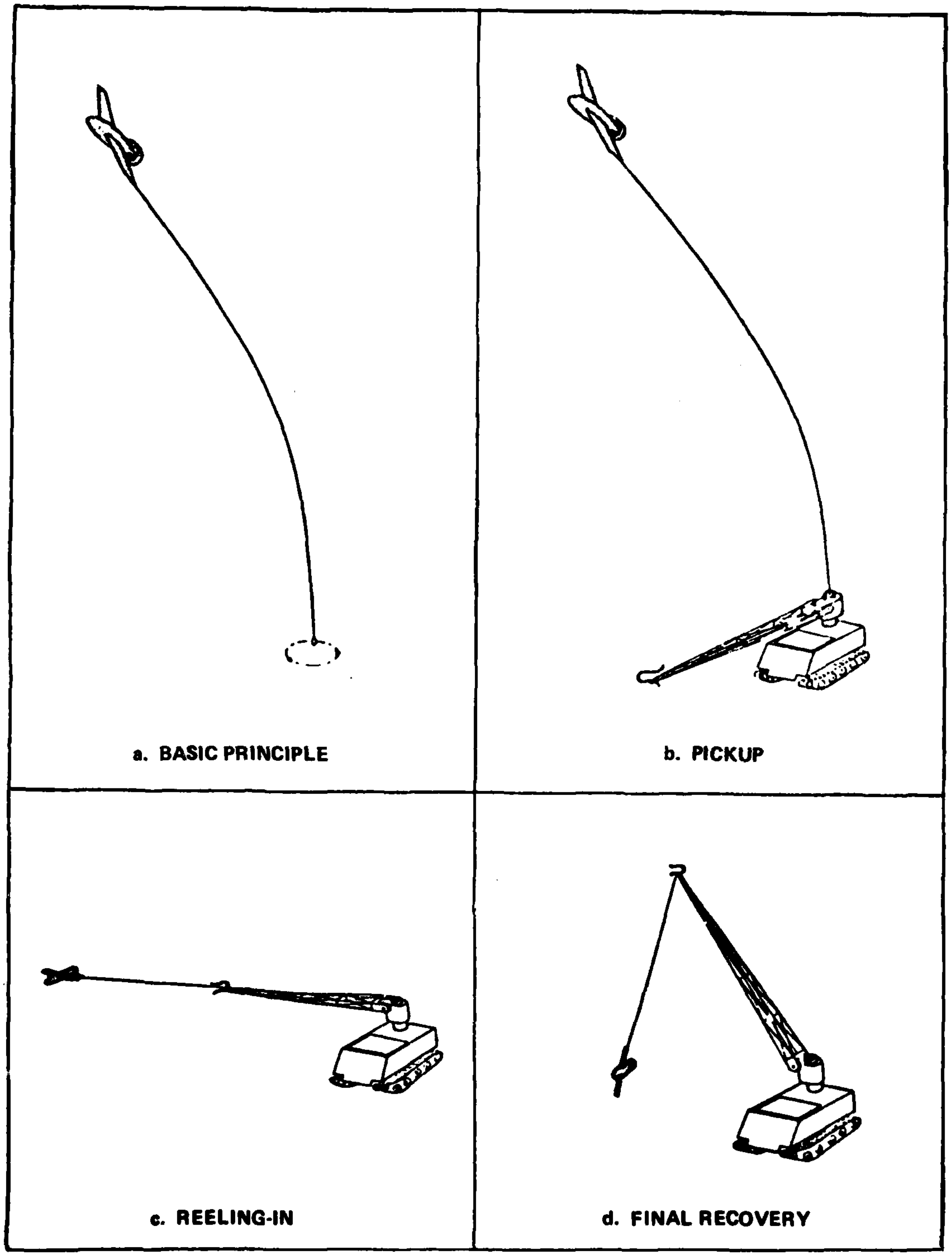


Figure 66. 'U' Control Recovery Concept

position below the aircraft and near the axis about which it is turning. The weighted end of the line will not remain motionless but will move around slowly in a small circle of a very short radius. Demonstrations of this concept have been made by raising a man from the ground by this means. The man on the ground simply reached out and grasped the end of the cable, attached it to his personnel harness, and was raised up and winched into the airplane.

TRA has conducted model tests of this principle for application to another purpose and possesses first-hand knowledge of satisfactory operations. In the present application, it is proposed that the RPV to be recovered be equipped with a deployable pendant cable properly weighted at the end. In operation, the RPV will be placed into tight circling flight, with pendant deployed, over the recovery site. The altitude of the RPV will be reduced until the weight at the end of the cable is close to, or resting on the ground. A man on the ground will grasp the end of the cable, move it over to the recovery vehicle, detach the weight, and hook the pendant cable to the winch cable in the recovery vehicle turret as shown in Figure 66. The RPV will then be commanded to shallow out its bank angle. This will result in the RPV's flying around in a circle in a plane somewhat off the ground in the manner of a conventional 'U' control model airplane but radio controlled. The turret of the recovery vehicle will then be placed in rotary motion and synchronized with the motion of the pendant (now tethered) cable. The turret boom will be raised to the level of the cable to cause the hook at its end to engage the cable. The tether cable will then be reeled in by means of the turret winch. This will cause the rate of rotation of the RPV about the turret axis to increase. The rate of rotation of the turret will be increased to adjust for this.

The RPV cannot be reeled in all the way to the tip of the boom, as the centrifugal load factor would exceed the prescribed limits for reasonable boom lengths and RPV minimum flying speeds. The RPV will be reeled in to a point where the length of cable extending beyond the tip of the boom is slightly less than the length of the boom. The RPV engine will then be shut down and the rate of rotation of the turret/boom slowly reduced. During this reduction, the boom will be raised to prevent the RPV from striking the ground. The RPV will lose lift and a vertical component of the tether line force is required to prevent it from sinking to the ground. Centrifugal force, due to boom rotation will also assist in keeping the RPV in the air. The rotation of the boom will be slowed further and the boom raised to compensate. This process will continue until the boom is stopped in nearly the vertical position with the RPV suspended from the cable.

It is to be noted that a modification of this system can be employed for launching the RPV.

A related patented (R. B. Cotton, Patent 3,351,325, Nov. 7, 1967) aerial pick-up and delivery system (Figure 67) employs a similar, but more complex system than the 'U' Control concept described above.

7.11.2 Analysis

Turn Maneuver Geometry

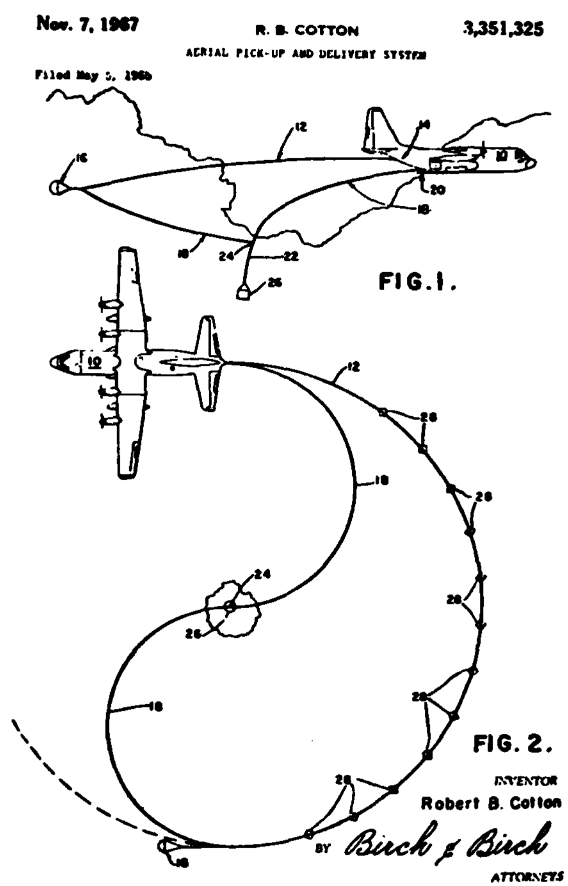
Figure 68 shows the geometry for a thrust-limited turn for the Aquila-type vehicle. The turn altitude is assumed to be a minimum of 1.5 times the diameter of the turn. The conditions represent stabilized turn performance after the RPV has completed the lowering of the cable and the initial quick turn to preclude the weight at the end of the cable from swinging out. The turn would be at about 800 feet altitude (D = 544 x 1.5) at a bank angle of about 63 degrees.

Window

Assuming the same approach window conditions used for several of the concepts in this study, the nominal conditions for a 6-degree flight path are shown in Figure 69. As in the case of the parachute, subsection 7.2.2, and the retro rocket, subsection 7.3, considerable latitude would exist for the target window, or the point at which the cable weight comes to its null point above the surface of the ground.

Wind Effects

Wind could upset the tranquility of the 'U' Control operation considerably. If the time to make one revolution is 13 seconds in a coordinated turn as indicated in Figure 68, a 20-knot wind would cause appreciable downwind drift from the point of entry. On-the-spot computations and commanded corrections flattening the turn upwind and steepening the turn downwind would alleviate the condition somewhat, but a circular ground pattern would be difficult if not impossible to maintain. With or without provisions to compensate for wind, the ground vehicle would have to maneuver considerably to keep the cable weight in proper relation to hook-up and



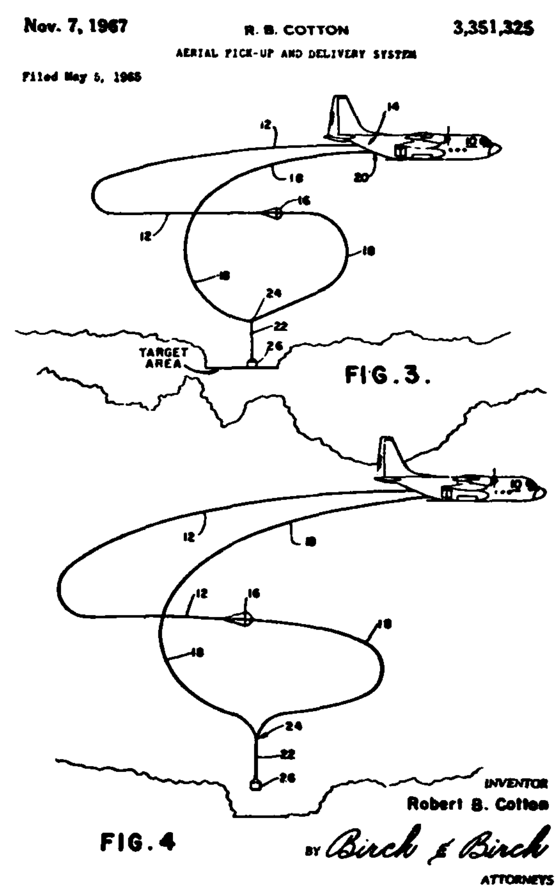


Figure 67. Patent, Aerial Pick-up Delivery

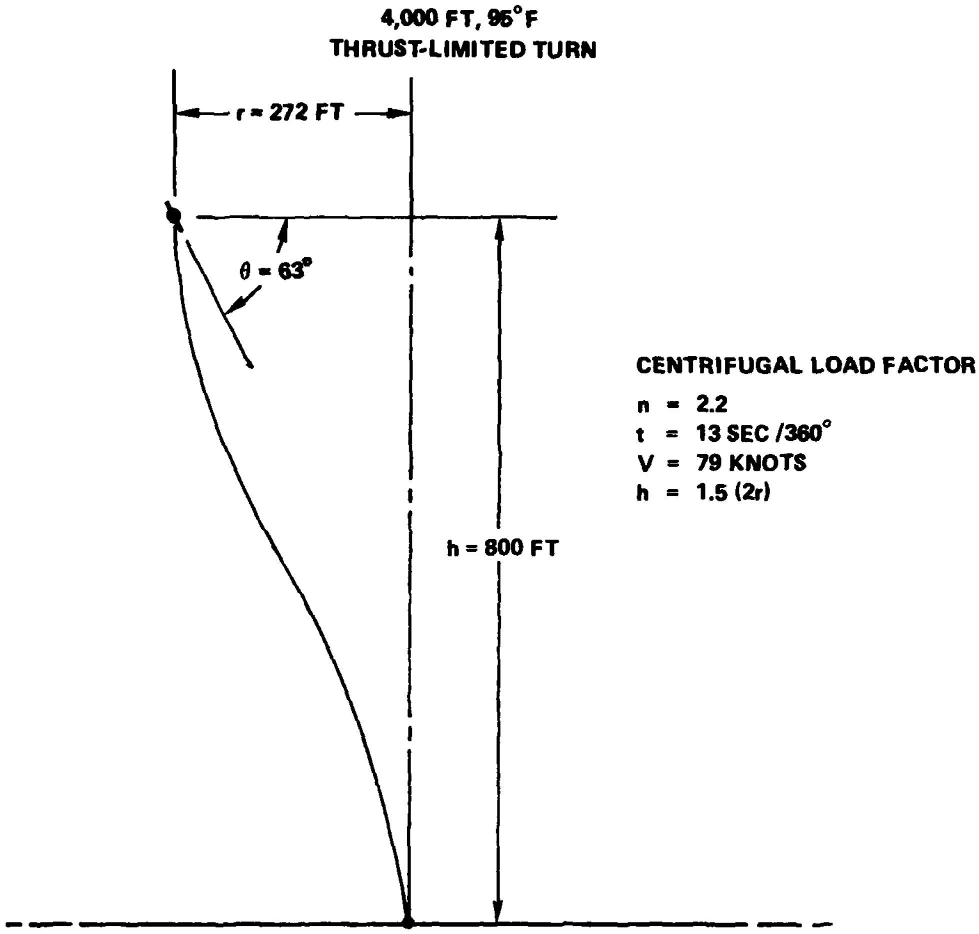


Figure 68. 'U' Control Recovery Flight Pattern

follow the RPV such that the line did not become too taut or too slack.

7.11.3 <u>Conclusions</u>. It appears that the 'U' Control recovery operation would take considerably more time, especially in wind conditions, than most other recovery systems. Although the RPV is a small object at about 800 feet altitude, the longer time exposes it to visual and perhaps other means of detection.

The 'U' Control concept would involve development cost and time for a rather sophisticated piece of ground equipment for the retrieval process.

Hazards related to the 'U' Control concept include controlling the approach flight path of the weight on the end of the long trailing line which responds differently from the RPV during velocity and flight path perturbations. Under such conditions the probability of snagging objects on or projecting above the ground exists.

The 'U' Control concept offers no apparent benefits that would offset some notable drawbacks including questionable reliability. It will therefore not be considered further as a candidate Mini-RPV recovery concept for U.S. Army operations.

7.12 Arresting Wire, Concept II-7

7.12.1 Introduction. The Arresting Wire category of Mini-RPV recovery concepts as used here, implies the use of a trailing hook deployed by the Mini-RPV to engage a horizontal wire, or wires, attached to an energy absorber as a basic means of decelerating the RPV. This basic principle had its beginning in the early days of Naval Aviation and continues to prevail as a means of recovering aircraft aboard ships. It also will be noted that the winch-down parachute concept, subsection 7.9.3, employs a similar means of engagement for recovery.

Three variations of arresting wire concepts will be discussed in the following section:

- 7.12.2 High-Wire Trapeze
- 7.12.3 Wires plus Impact Platform
- 7.12.4 Wires plus Chute plus Impact Platform

7.12.2 High-Wire Trapeze, Concept II-7A

a. General

The high-wire trapeze version of the arresting wire category, as will be seen in Figure 70 includes a horizontal arresting wire stretched between two stanchions. The wire passes over pulleys attached to the upper ends of each stanchion, then down to energy absorbers.

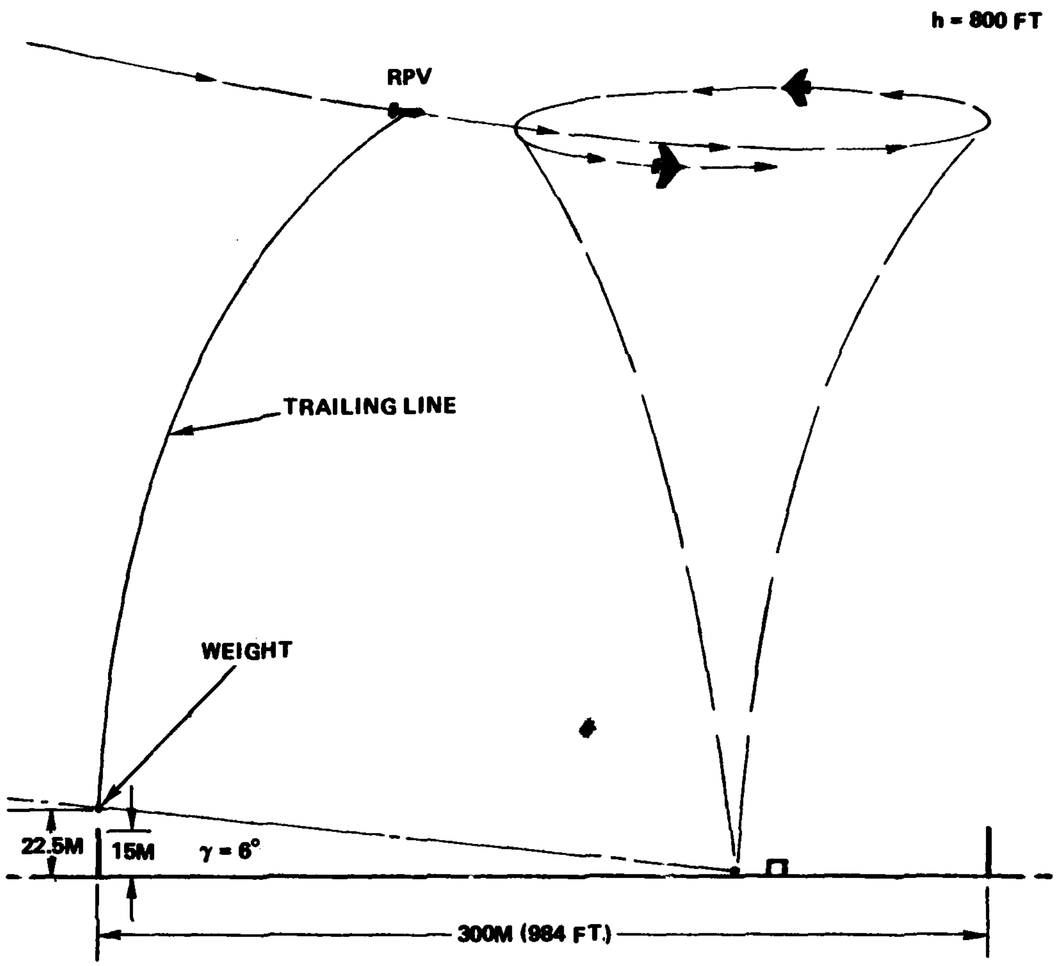


Figure 69. 'U' Control Recovery Approach Segment

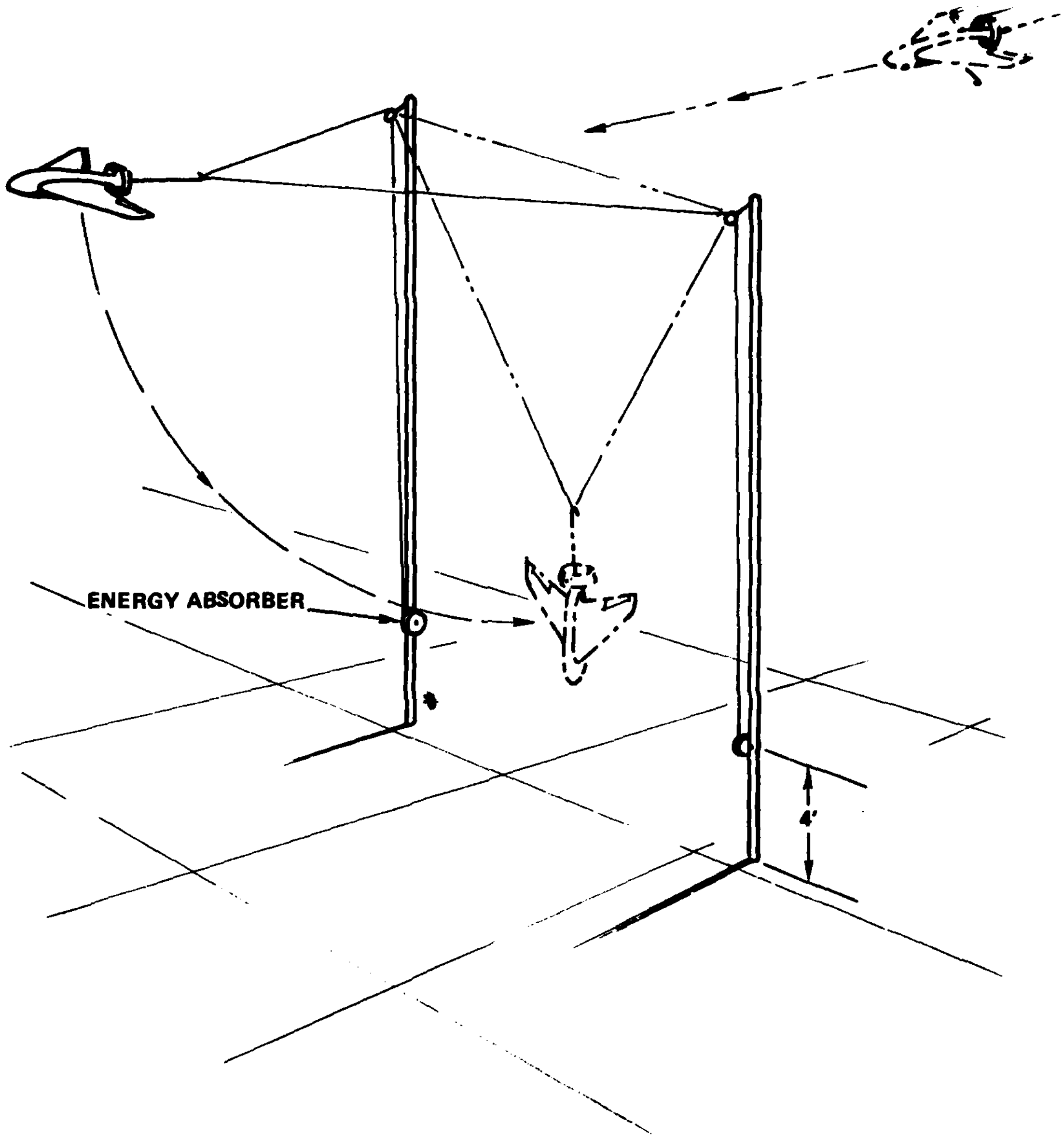


Figure 70. High-Wire Trapeze Recovery Concept

The RPV, in the terminal guidance mode, approaches the horizontal wire with hook deployed. After engaging the horizontal wire, the RPV travels forward and decelerates to zero velocity under the action of the retarding forces generated by the energy absorbers. As the RPV decelerates, it is dropping vertically under the action of gravity and finally swing back between the stanchions. After the pendular oscillations die out the RPV would hang a few feet above the ground in the retrieval position.

b. <u>Analysis</u>

The ideal run-out, or deceleration, distance for the RPV traveling against the energy absorbers is the same as for the retro rocket of subsection 7.3, since a constant retarding force is assumed. Under like assumption, the distances for various decelerations would be

	ℓ_d, ft	
g's	120-lb RPV	200-lb RPV
3	37	90
6	19	45
12	9	23

The major concern with the run-out distances is how they affect the total height of the support stanchions. Some increase in the design length of the lines could be expected due to inelastic behavior of the system and to the difference between ideal distances and those of actual practice. Other dimensions that add to the total height of the stanchions are: the clearance between the ground and the RPV, the length of the RPV, and the length of the trailing hook.

The total height of the stanchions could then be expressed as:

$$h = (\ell_d K)1.05 + 4.0 + 6.0 + 8.0, \text{ ft}$$

where

ℓ_d = ideal run out length
K = factor for actual practice
1.05 = inelastic (stretch) factor
4.0 = ground clearance
6.0 = length of RPV

8.0 = length of hook

The K factor for the wire system would have to be determined by analysis, and perhaps tests. However, if we estimate K as 1.2 for the purpose at hand, the total height of the stanchions for 12 g deceleration would be:

	120-lb RPV	200-lb RPV
h =	29 ft	47 ft

The stanchion height could be reduced further at the expense of some complexity by means of a line retraction system. By initiating retraction of the lines slightly before the end of the normal run-out is reached, it is possible to shorten the swing height of the RPV.

The airborne weight of the hook, its deployment system, and controls is estimated not to exceed 5 percent of the RPV's gross weight.

Target Window

The target window at the engagement point is a function of the trailing hook's length for the vertical dimension, and the distance between the stanchions for the horizontal (width) dimension. The basic dimensions are, of course, modified by practical considerations. The effective vertical dimension of the window would depend on the dynamic response of the hook at various points along its length, as it impacts the wire. Assuming that the RPV would always be above the wire (and tops of the stanchions) the wing tips would not be a limiting condition. Window width dimension would be limited by how far off center the hook could engage the wire without causing untenable dynamic problems due to asymmetric loading of the energy-absorbing system and the friction of the line sliding through the RPV's tail hook.

A rough estimate of usable window dimensions for stanchions 25 feet apart is: height, h, = 6 feet, and width, w, = ± 4 ft.

Wind Effects

With means provided to meet the wind shift requirement (180 degrees in 5 minutes) operating in a 20-knot headwind would be mostly a matter of determining operating limits for the recovery and terminal guidance system. That is, letting the relative speed (the energy level) of the RPV get too low may not be compatible with the energy absorption system or the terminal guidance system.

c. Conclusions

The basic principle of engaging an arresting wire with a tail hook deployed by an air vehicle for the purpose of decelerating the vehicle to zero velocity is credible in view of past experience with aircraft carriers and a few land-based installations. However, the carrier-type system has the advantage over the free flight hook-up in that the hook is positioned a fixed distance from the wire by the surface of the deck.

The major problems with the high wire trapeze recovery system appear to be related to hitting a relative small target window accurately enough to achieve hook engagement and to preclude dynamic problems leading to recovery failures.

The airborne weight involved is estimated to be acceptable.

7.12.3 Wire Plus Impact Platform, Concept II-7B

a. General

The wire and impact platform recovery concept illustrated in Figure 71 incorporates a wire engagement and energy absorption system similar to the high-wire trapeze concept of subsection 7.12.1. After the wire is engaged, and the RPV runs out against the retarding forces of the energy absorbers, it drops on a resilient platform which absorbs energy in the vertical direction.

This basic system employing resilient tapes for the platform was used to recover the XMQM-105 Aquila RPV in its early stages of development. A sloped bank of arresting wires was used instead of a single wire.

Another form of impact platform that may be used with the wire arresting system is the inflatable air bag referred to in subsection 7.6.4.

b. Analysis

In lieu of actual data on the wire/impact platform

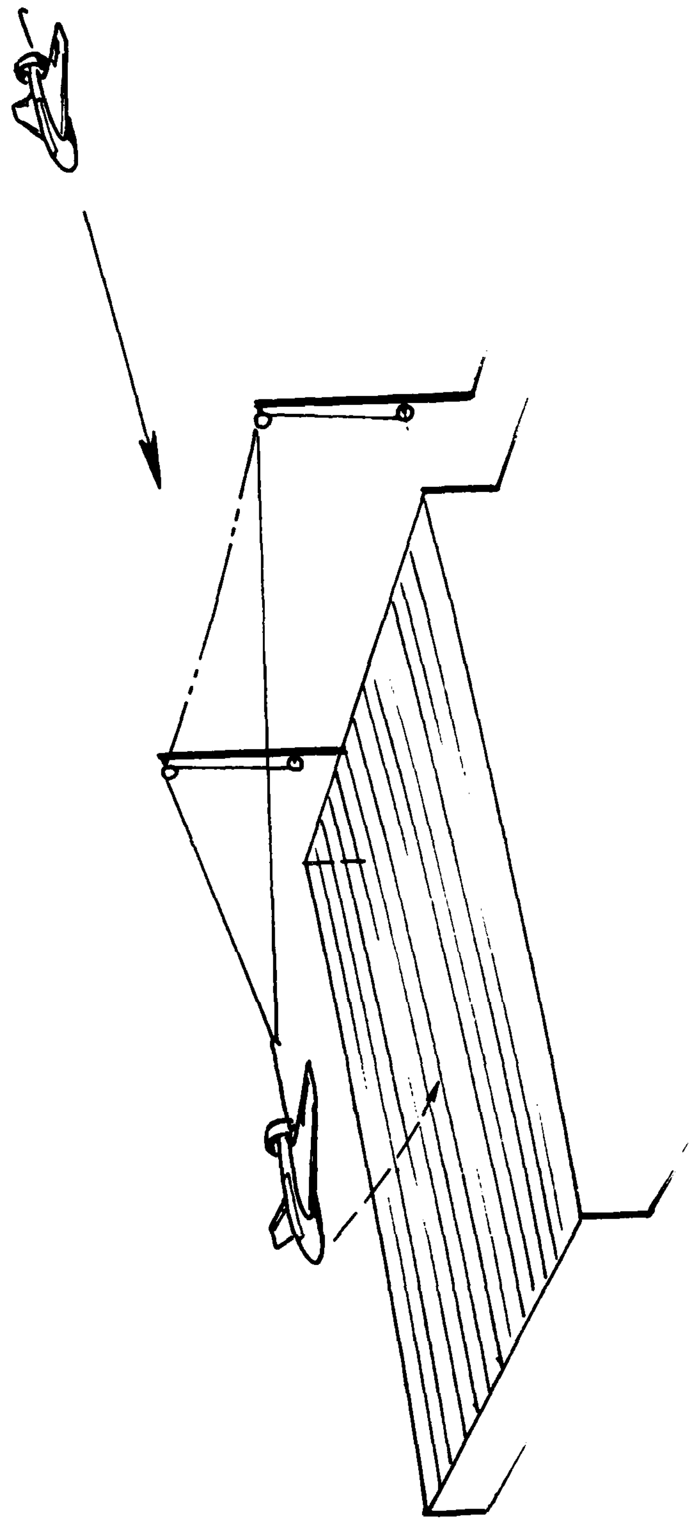


Figure 71. Wire Plus Impact Platform Recovery

recovery operations, it will be assumed that the performance is similar to that for the capture net and impact platform of section 7.6.4.2. There appears to be no particular advantage in seeking the higher g decelerations (8 to 12) for this concept as there might be for the high wire trapeze where the height of the stanchions becomes prohibitive at low g.

Target Window

Same as under 7.12.2 b.

Wind Effect

Same as under 7.12.2 b.

c. Concluding Remarks

The meager amount of test experience with the arresting wire(s) plus impact platform indicates that the concept is credible.

The major problems with the wire and impact platform recovery system, similar to the high wire trapeze, appears to be related to hitting a relatively small target window accurately enough to preclude dynamic problems related to hook engagement and hence incipient recovery failures.

The airborne weight involved is estimated to be acceptable.

7.12.4 Wire Plus Impact Plus Chute Concept, II-7C

a. General

As will be seen in Figure 72, the wire plus impact plus chute concept is intended to offer an omnidirectional approach to the recovery platform. Supported by a high-glide chute, and trailing a hook, the RPV flys under power toward a circular impact platform which is surrounded by a peripheral wire supported by several posts. When the hook engages the wire, the RPV would be decelerated as the wire stretches, and it would then drop on the resilient platform. The RPV's rate of descent would be checked by the hi-glide chute flying at very high angles of attack (about 80 to 90 degrees), in which case the hi-glide chute would have drag characteristics similar to a circular chute.

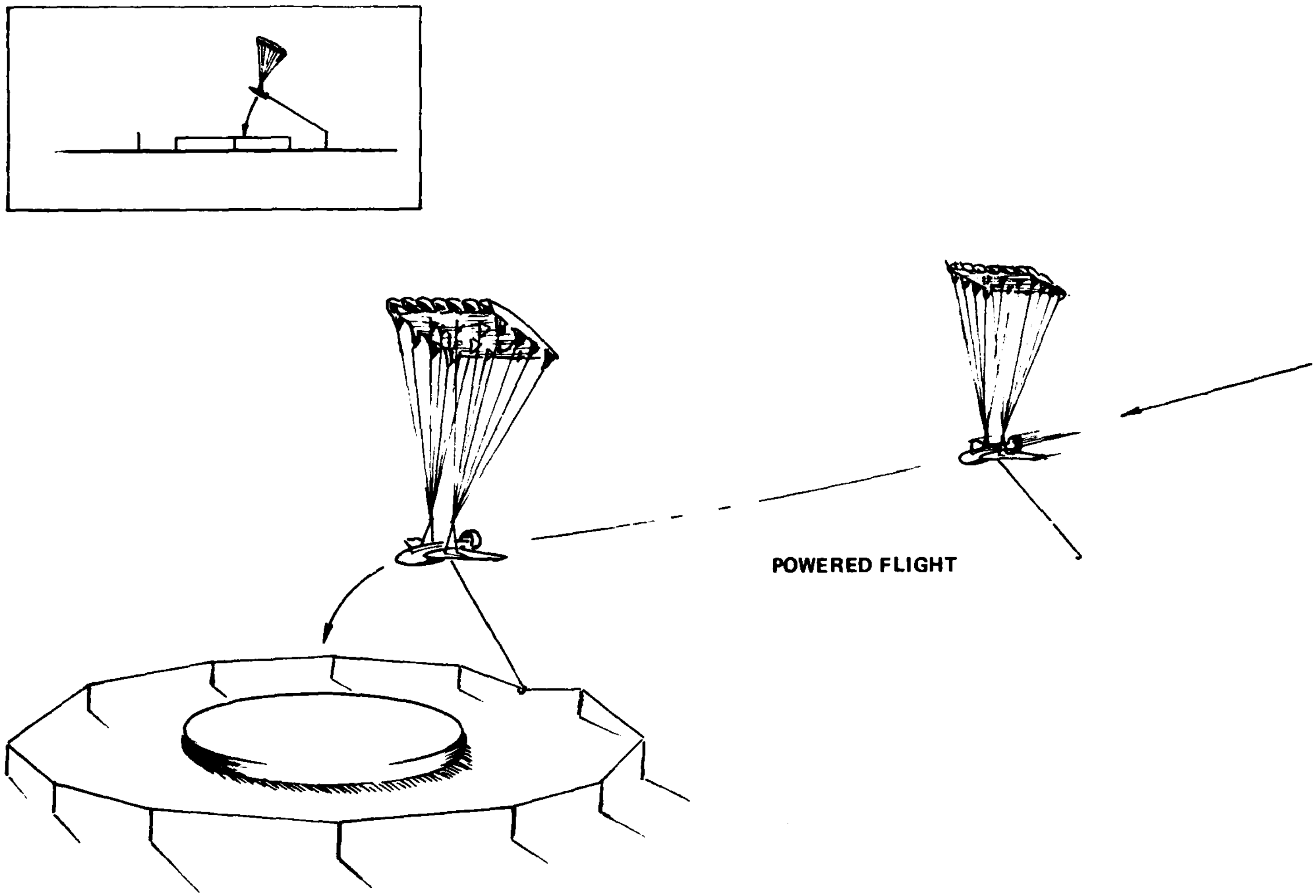


Figure 72. Wire plus Chute plus Impact Platform Concept

b. Analysis

Assuming that the middle size hi-glide chute of subsection 7.9.5 b was used, the RPV would be traveling about 24 knots in still air as it approached the recovery system. For the 200-pound class RPV, the kinetic energy would be about 5284 foot-pounds, or about 1/10 that of a free flight RPV approaching at 78 knots. Assuming that the retarding load due to stretching the wire came on linearly, the energy could be ideally absorbed in about 2(2.2) = 4.4 feet for 12g; 8.8 feet for 6g; or 11.6 feet for 3g. Unless special provisions were made, the wire could be expected to take back some of the energy thus the RPV may back up somewhat before impacting the platform. Thus with the low energy level involved no serious problems with bringing the RPV to rest would be expected.

The length of the trailing line would be several times the length of the RPV to give the hi-glide chute time to change modes thus better controlling the terminal vertical velocity. The small sketch on Figure 72 indicates, to scale, a 50-foot trailing line, a platform 70 feet in diameter, with the engagement wires, 120 feet across the flats of the octagon.

Target Window

The effective width of the window would be approximately 30 feet. The upper limit of the window height is the height of the engagement wire. The lower limit is assumed to be with the trailing hook about 2 feet off the ground. Thus the window height should be the height of the poles minus 2 feet, or 6 feet for 8-foot high poles. Theoretically the RPV could fly much lower by dragging the trailing line on the ground. However, in view of the indefineable number of terrain situations likely to be encountered, the chances of the hook snagging something on the ground are estimated as great.

Wind Effects

In a 20-knot headwind, the RPV would be at 4 knots ground speed. With power on until impact occurred, the touchdown should be very gentle. An automatic chute release is assumed in any case.

c. Conclusions

The arresting wire plus chute plus impact platform concept has some attractive features in that the recovery process involves low energy levels and unsophisticated energy-absorbing devices.

The major disadvantage of the system is its inherent incompatibility with the intended operations in a tactical environment. Since burying the poles in the ground would not be allowed, some other form of mounting would be required, implying an excessive amount of ground installations and/or vehicles.

In any event, during the time required to erect and dismantle the system, if not in excess of the limits specified for this study (4 men, 1 hour to erect, 30 minutes to dismantle) plus some lead time in anticipation of the RPV's arrival, a large visual signature would be exposed.

The weight of the airborne equipment (chute plus steering system plus trailing wire/hook) is estimated to exceed the desired limit of 7 percent of the RPV's gross weight.

In summary, the wire plus chute plus impact concept does not appear to be a suitable candidate for the intended U.S. Army Mini-RPV recovery operations.

7.13 Tethered Aerial, Concept II-8

7.13.1 General. The term "tethered aerial" as used here denotes a concept involving a line, or lines tethered to a ground vehicle, or implacement, with the upper end of the line supported by an aerostat, a wind-dependent gliding chute (kite), or a powered rotary wing device.

The balloon-supported recovery concepts are unacceptable for the intended U.S. Army field deployment chiefly because of the untenable visual signature which would be present over a relatively long period of time involved in deploying and retrieving the balloon system.

The wind-dependent concept is also unacceptable because of the unpredictability of the wind in field operations.

However, the aerostate and wind-dependent concepts are discussed briefly below.

7.13.2 Aerostat, Concept II-8A

a. Cable Capture

The aerostat shown in Figure 73 (a) employs a balloon to support a tethered cable. The lower end of the cable attaches to a winch to reel in the balloon, and/or the RPV after it is captured.

The RPV would be flown close enough to the vertically suspended line that a hook/latch device mounted on its wing tip (similar to the Rotary/Carousel concept, subsection 7.8) would lock onto the cable. Detents swaged to the cable at intervals would keep the RPV from sliding down.

The aerodynamic drag of the balloon and its bouyancy would presumably provide a relatively soft damping effect after the RPV impacts and attaches to the line.

b. Net Capture

Another form of Aerostat, a tethered capture net supported by two balloons is illustrated in Figure 73 (b). This concept was presented in Reference 14. Very probably either separate lines or a spacer bar would be required to prevent the ends of the net from pulling together.

In this concept the effect of the balloon's drag and bouyancy, and the drag of the net would provide considerable damping. Retaining the RPV in the net at the end of the stroke would appear to be a problem.

7.13.3 Wind-Dependent, Concept II-8B. Two wind-dependent concepts are noted below.

a. Flexible Fabric Wing-Supported Recovery Net

The flexible fabric wing-supported net concept Figure 74 is described in more detail in Reference 14. This concept is similar to the balloons supporting a net. The lift for the wind-dependent concept would be supplied by a high aspect ratio volplane hi-glide chute (Reference 14). This concept also appears to have good damping qualities. The problems with capturing the RPV securely would be much the same as for the aerostat concept.

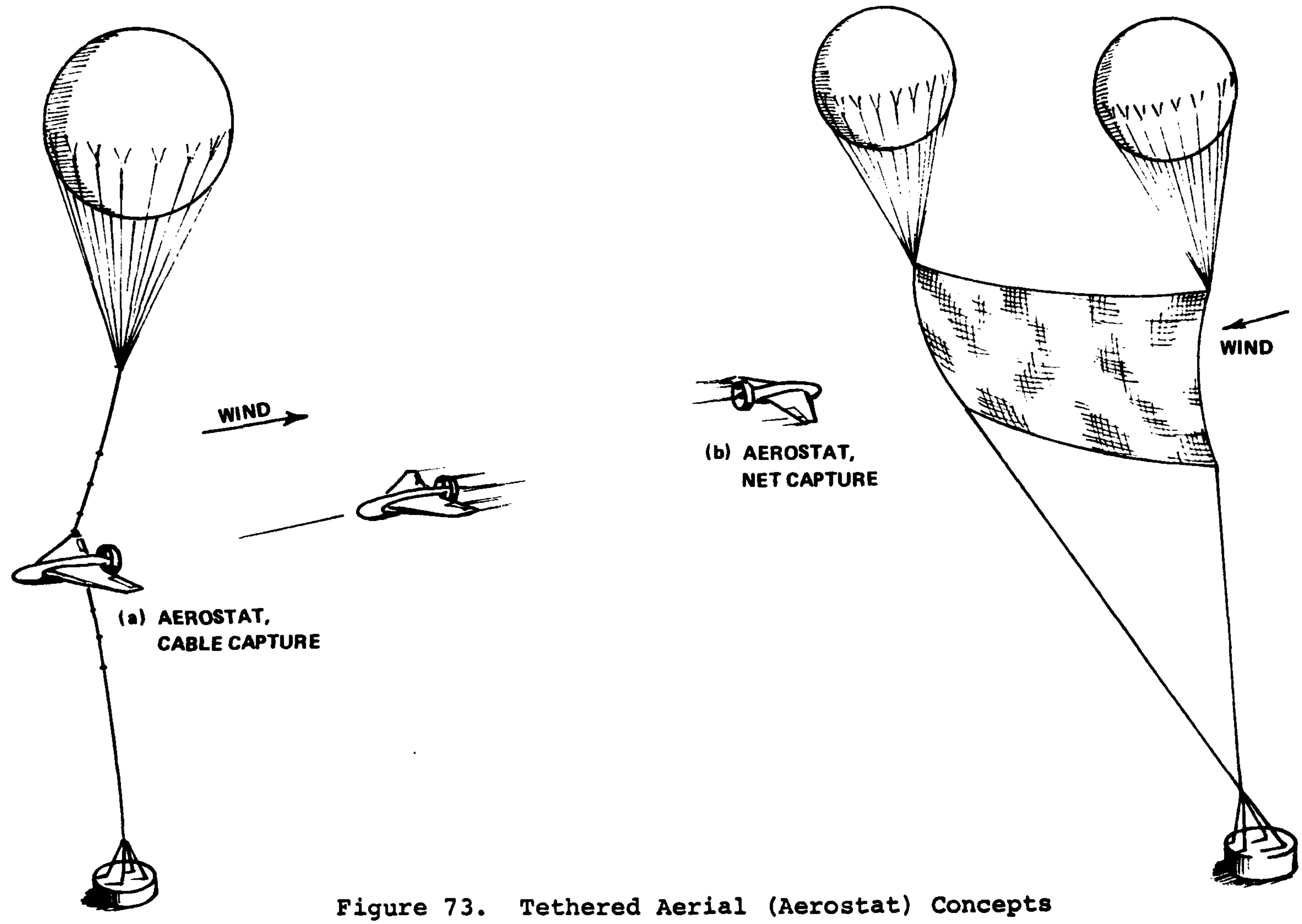


Figure 73. Tethered Aerial (Aerostat) Concepts

b. Moored Wing Recovery Concept

The moored wing concept, Figure 75 is also from Reference 14 from which the following paragraph is excerpted:

"The proposed concept would employ a grappling hook, deployed at chute deployment and attached to the nose of the vehicle by a light nylon line of perhaps 400 foot length. As the grappling hook dragged the surface of the recovery area, the attaching line would exert a turning moment on the vehicle (and wing), causing it to yaw around and fly toward the mooring point, normally upwind of the vehicle. This process would be repeated whenever the grappling line was drawn taut. This approach would require the vehicle be coupled to the wing in the proper orientation."

It appears that a directional control system would be required for this concept. In addition to the overall objections to wind-dependent systems noted in 7.13.1 above, the uncertainties posed by the use of a grappling hook would be a minus for this concept.

7.13.4 Rotary Wing, Concept II-8C

a. General

The tethered aerial system of Figure 75 employs a powered rotary wing vehicle to support a tether cable and a beam with dangling engagement lines to provide additional window width for capturing an RPV. This system involves snagging the RPV by a wing-tip-mounted hook/latch system similar to the rotary (Carousel) concept of subsection 7.8.

The rotary wing concept would utilize an unmanned helicopter such as the Dornier Do 34 Kiebitz (Reference 29) which, for example, is powered by a "cold-jet" rotor driven by compressed air from a turbine engine/ radial compressor unit.

The complete system is housed on a land vehicle and consists of the flight vehicle, a landing platform, winch system, guidance and control post, a checkout system, a fuel tank with capacity for 12 hours hover time, and miscellaneous auxiliary equipment. Fuel for the turbine is fed through the tether by means of a pump installed in the ground vehicle.

As shown in Figure 75, after being engaged by the RPV, the dangling line would run-out against an energy-absorbing device. The helicopter platform would be flown at altitudes of 200 to 300 feet thus providing sufficient distance for cable run-out to keep the RPV's rate of deceleration low.

When the tether line is engaged by the RPV, the energy will presumably be absorbed, more directly by the aerodynamic damping afforded by the helicopter platform.

After being captured, the vehicle could be lowered to the ground by the helicopter platform.

b. Analysis

No attempt will be made here to apply even cursory computations to the rotary wing recovery concept. However, some of the apparent problems with the system will be reviewed in qualitative terms.

The first problem to be addressed is the behavior of the dangling engagement lines when they are impacted by the RPV. It appears that at least three response modes, and perhaps combinations of them, could occur: (1) the line being impacted near its lower end may bounce away without engaging the hook/latch at the tip of the wing of the RPV, (2) the line being impacted close to its upper end (especially if the point of impact is near the root end of the RPV wing) where the inertia of the lower part of the line would inhibit the line from sliding

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29. Taylor, John W. R., JANES' ALL THE WORLD'S AIRCRAFT, JANES' YEAR BOOKS, London, 1974-1975.

outboard on the swept leading edge toward the hook at the wing tip, and (3) intermediate points of impact where the "bola", or wrap-around, effect occurs.

The detents spaced at intervals along the dangling lines for the purpose of preventing the cable from running through the hook/latch device are a potential source of damage to the RPV's wing leading edge.

The dangling line could run over a pulley and back along the support beam to an energy absorber mounted on the helicopter platform, or the line could be attached to the beam with a temporary tie. This would allow the line to pull at the center line of the helicopter platform after the tie was broken.

In the former case, the RPV would apply appreciable yaw and roll moments to the helicopter platform during deceleration and swing back. To minimize the magnitude of the upsetting moments, the deceleration load factor for the energy absorber would have to be set for low values, and consequently long runout distances. In this connection, ideal deceleration distances are 135, 150, and 210 feet for 1, 1.5, and 2.0 g, respectively. Although the Dornier type helo platform is stabilized about 3 axes, it is doubtful that the restoring forces available would accommodate all of the upsetting moments generated by a 200-pound RPV pulling at distances of 10 to 20 feet off center.

In the latter case with the RPV running out from the centerline of the helo platform the main disturbance would be the translating effect on the helo created by the RPV's energy. This same effect would, of course, occur with the pull applied to the beam outboard of the helo centerline. With the pull-at-centerline arrangement, the RPV would most likely strike the tether cable as it swung back after it decelerated.

Target Window

If contact anywhere along the dangling lines resulted in a successful engagement, the window dimensions would be relatively large. The height, h, would be the length of the line (except for the tether line) and the width, w, would be the distance between the outside lines plus approximately one wing span (half span outside of each end line).

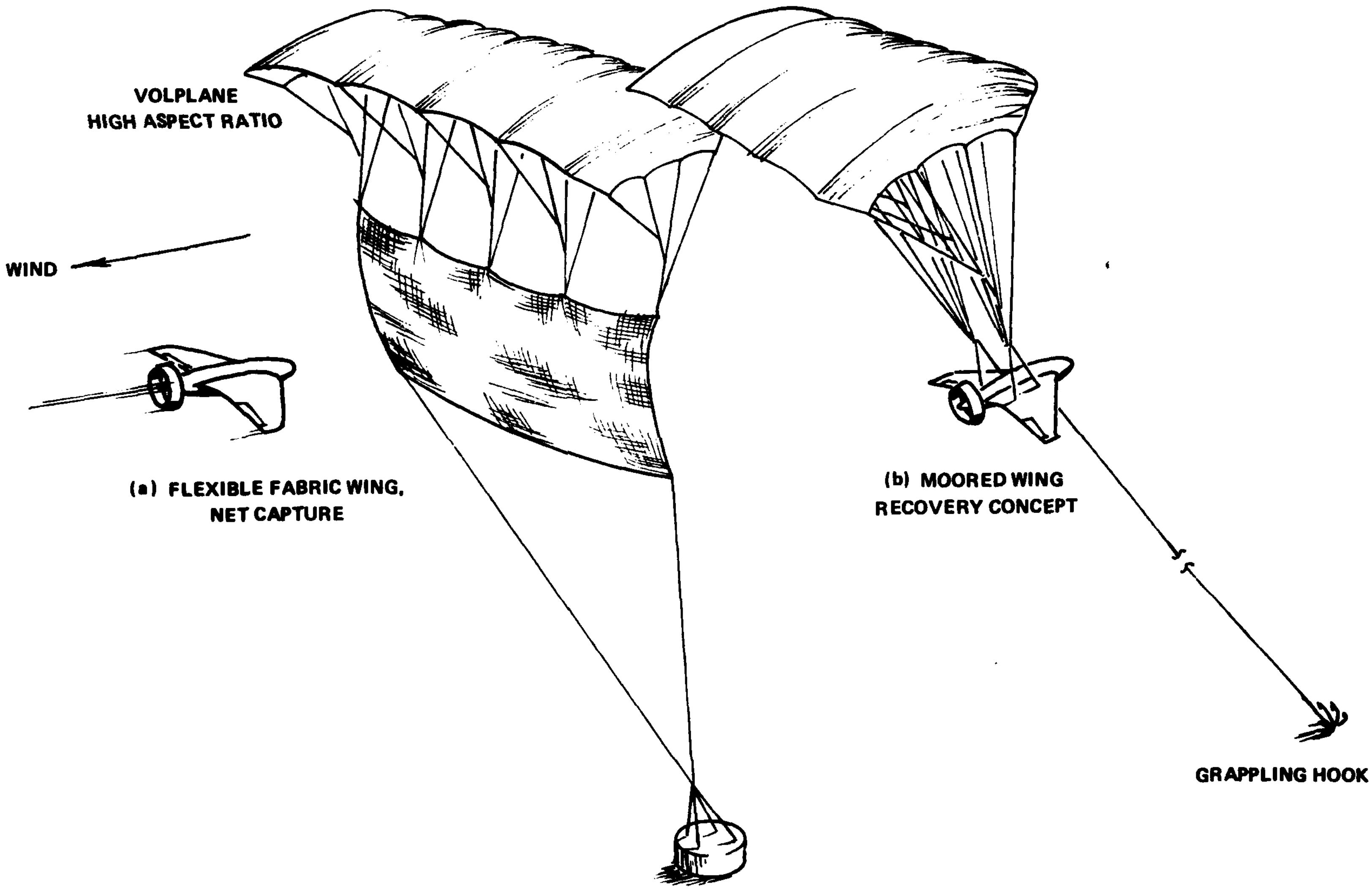

Figure 74. Tethered Aerial Wind-Dependent Concepts

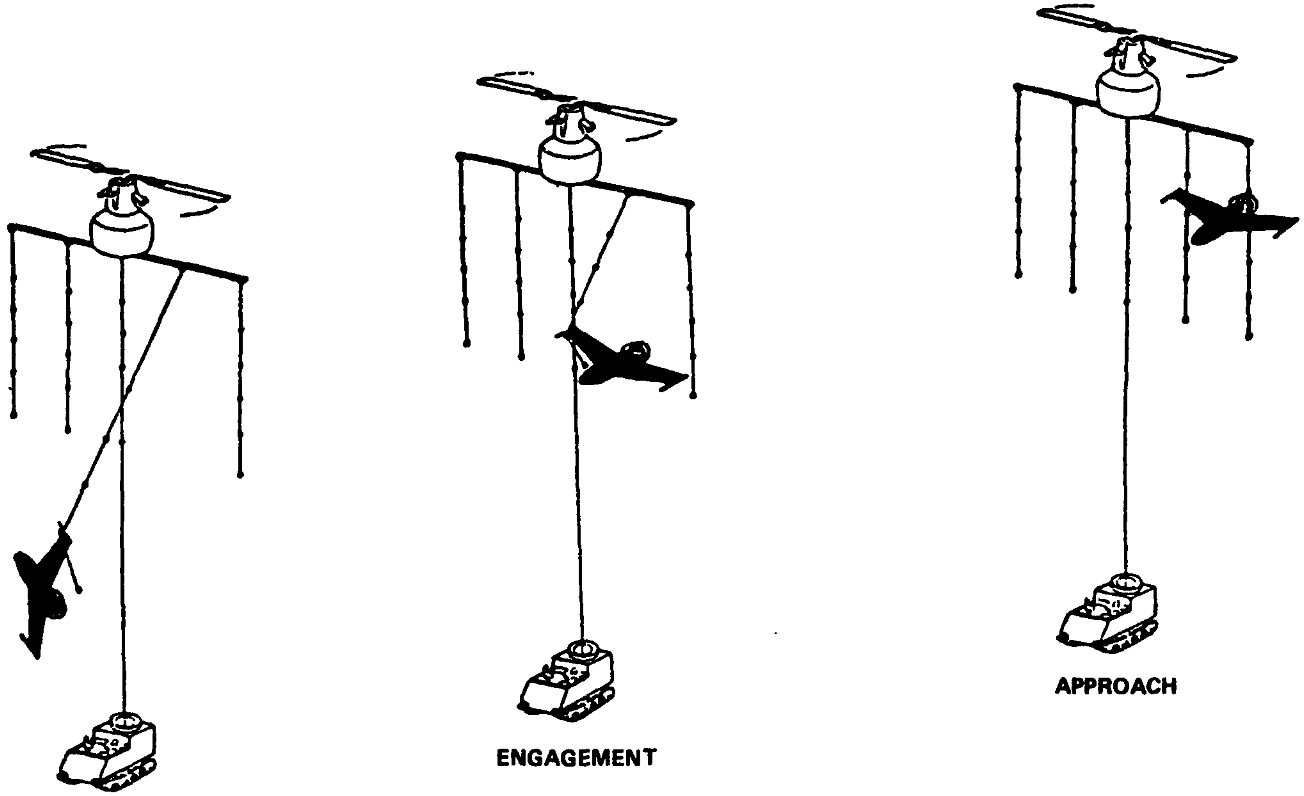

Figure 75. Tethered Aerial, Rotary Wing

Wind Effects

The tethered helicopter under consideration would be relatively unaffected by wind as far as drift is concerned. The Dornier type machine, it is claimed can compensate for winds up to about 27 knots or 46 ft/sec (Reference 29).

c. Conclusions

Without even considering the variety of development problems to be solved, it is safe to state that the cost of the helicopter platform plus the special ground vehicle would, conservatively, be approximately 5 to 10 times that of the typical traveling net recovery system investigated in this study.

The visual, and perhaps other forms of signature, would be substantial with the helicopter platform deployed 200 to 300 feet above the recovery area for RPV recovery.

Hazards to personnel and ground equipment due to a possible collision between an RPV and the helicopter are to be considered.

In summary, the tethered rotary wing concept appears to be unacceptable for the intended Mini-RPV recovery requirement for U.S. Army tactical employment.

7.14 Brush Attenuator, Concept II-9A

7.14.1 General. The brush attenuator recovery concept (Reference 21) is patterned after a recovery system found in nature; that is, model airplanes landing successfully in grain fields or tall weeds due to the progressive energy absorbing characteristics of the flexible stems.

The system shown in Figure 76 would utilize long nylon flexible members (oversized bristles) to arrest the forward motion of the RPV as well as to cushion its vertical velocity. The bristles are arranged in modular trays which can be linked together by means of latches. The bristles fold down into their respective trays for transport or storage and are errected by the turning of a crank to form a landing bed for the recovery operation.

7.14.2 Analysis. First, the size of the brush attenuator landing bed is estimated. The width is assumed to be similar to that of a recovery net, or about 25 feet minimum. The length can be approximated by assuming a desired maximum average deceleration in terms of g. The basic nature of the brush system does not seem compatible with high-g decelerations, such as the 12g maximum allowed in this study. A compromise of 6 g will be assigned. The ideal length for the 200-pound class RPV at 78 knots would be:

$$\ell_d = V^2/2gn \tag{36}$$

$$= 78 \dot{x} \; 1.69/64.4 \times 6$$
$$= 45 \text{ ft}$$

This length is optimistic in that a constant decelerating force, an ideal condition, is implied.

In lieu of any means whatever with which to make a cursory approximation of the height, a distance of 8 to 10 feet will be used. The effective height of the attenuator system would be appreciably less than its actual dimension. If the RPV impacts too low, the resistance will be quite high. If it impacts near the top it would undoubtedly tend to skip out like a flat rock on water.

Sizing the bristles would require in-depth and intricate analysis, and the design would very likely accommodate only one RPV in a limited approach speed range.

Like other proposed Mini-RPV recovery schemes based on experience with model airplanes, a concept can lose its viability as it is scaled up because of the vast differences in kinetic energy to be absorbed. By way of comparison, the energy levels for an 8-pound model airplane at 40 mph and the two basic Mini-RPV's of this study are tabulated below:

	MODEL	120-LB RPV	200-LB RPV
Design V, ft/sec	68	84.5	131.82
KE , ft-lb	574	13305	53964
Ratio	1.0	23	94

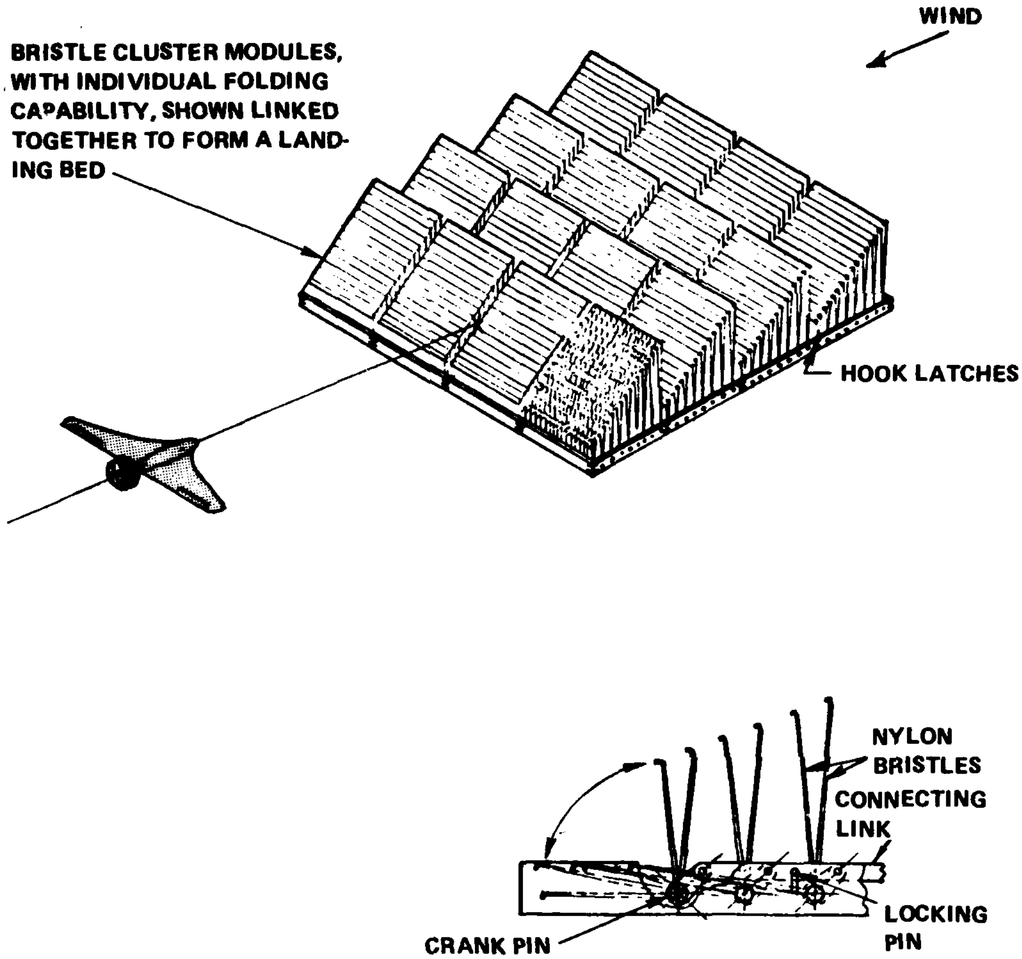

Figure 76. Brush Attenuator Concept

This kinetic energy comparison of itself does not say that the brush attenuator problems could not eventually be solved. However, we have seen within this study report (the rotary Carousel, Section 7.8) that a concept becomes unwieldly and questionable as the parameters for the 120-pound RPV are increased to accommodate the 200-pound RPV.

Wind Effects

The turbulence on the downwind side of the brush attenuator unit due to a 20 knot wind could adversely affect the flight behavior of the RPV as it approaches the impact point. Maintaining the true speed to match the design energy level by adding power in wind conditions may be found necessary as with some of the other concepts in this study.

Target Window

Overall, the target window would be similar to some of the net and tail-hook concepts. The effective height of the window would have to be considered as noted above.

7.14.3 Conclusions. The modular brush attenuator landing bed could undoubtedly be made mobile with no more than two trucks, and the time to erect and disassemble could conceivably be within limits. However, its bulk (about 1145 feet, 8 to 10 feet high) when assembled provides a large visual signature that would be exposed for relatively long periods of time.

Retrieving the RPV from the middle of the bristle complex would also be a problem.

Perhaps the overriding concern with respect to the brush attenuator is that the mechanical feasibility of the concept appears to have questionable aspects that imply appreciable technical risk.

In summary, the brush attenuator recovery concept does not appear to be a suitable candidate for the recovery of Mini-RPV's in U.S. Army field operations.

8.0 PRELIMINARY EVALUATION AND CONCEPT SELECTION

Descriptions, analysis, and comments on the advantages and disadvantages of each of the 27 Mini-RPV recovery concepts categorized in Table 1 are presented in Section 7.0 of this report. Seventeen of the concepts were set aside by agreement of a joint Army/TRA Committee on 15 December 1976. A list of those concepts that were set aside, and a summary of the reasons is presented in Table 7. Data on which these reasons were based vary among the concepts from reasonably good quantitative information to purely subjective engineering judgements. Therefore some of the reasons for setting aside a given recovery concept are heuristic in nature. However, it is felt that those concepts chosen for further evaluation are significantly better than those that were set aside.

The ten concept categories to be carried over for Phase II studies are shown in Table 8.

TABLE 7. CONCEPTS SET ASIDE IN INITIAL EVALUATION

Group I, Surface Impact

Concept	Remarks
• Runway, I-1	
	• Tactically unsuitable (300M too short for 200-lb, 70K class RPV)
	• Pre-preparation of site required
	• Large signature as observed from the air
• Parachute, I-2	
Transferred, I-2B	• Reliability factor estimated low
	• Extreme accuracy for guidance and control required
	• RPV oscillations on long chute riser line
	• Pyrotechnic hazards and logistics
• Fabric Rotor, J-2C	
	• Signature (higher altitude to deploy)
	• Reliability (complex deployment sequence)
	• Rotor weight, stowed volume and deployment requirements incompatible with Mini-RPV
	• RPV damage and hazards due to rotor energy at ground impact

Table 7, Continued

• Stowed Rotor, J-4	
	• Major damage to RPV with each recovery
• Spin Recovery, I-5	
	• Major damage to RPV with each recovery
Group II, Above-Surface-Recovery	
• Capture Net, II-1	
Fixed/Articulated, II-1A	
	• Inherently inadequate energy absorber for 120- to 200-lb class RPV • Experience unsatisfactory with 100-lb RPVs
• Inclined Ramp, II-2	
Friction, II-2A	
	• Excessive size of recovery system hampers mobility • Signature large as observed from the air • Feasibility of large ramp concept questionable
Friction Plus Auxiliary Decelerations II-2B	
	• Adding auxiliary deceleration schemes to reduce size of ramp leaves little distinction between this concept and II-1C and II-7B, with no apparent advantages

Table 7, Continued

Parachute, II-4

MARS, II-4A

- Signature large
- Cost and availability of dedicated helicopter and crew for each Mini-RPV section is incompatible with intended Mini-RPV operations
- Safety hazard in exposing Helo and crew to enemy fire

Deceleration Chute Plus I.P., II-4C

- To achieve horizontal or near-horizontal impact of RPV requires chute deployment at altitudes of 20 feet and under
- Precise guidance and control and chute deployment timing required to hit two successive target windows

- Aerial Track, II-5

  - Concept is actually serving same purpose as a long run-out capture net. Useful only if low g-loads (2.0) are necessary.
  - Long distance between truck mounted stanchions
  - Appears to have no advantage over the more compact recovery systems

Table 7, Continued

• <u>'U' Control, II-6</u>	
	• Reliability (cross winds, etc.) factor low
	• Development of sophisticated ground vehicle for RPV undesirable
	• Large signature while circling at up to 800 feet altitude
• <u>Arresting Wires, II-7</u>	
Wire Plus Chute <u>Plus I.P. II-7C</u>	
	• Incompatible with mobility requirements
	• Reliability (grappling hooks) factor low
	• Signature is appreciable from the air
<u>Tethered Aerial, I-8</u>	
<u>Aerostat, II-8A</u>	
	• Long visual and other signatures, of relatively long duration
	• Reliability (capture and retrieval of RPV) estimated low
	• Logistic supply (helium), and ground support problems

Table 7, Continued

Wind-Dependent, II-8B	• Signature (helo platform at 200 to 300 ft) of relatively long duration • Not feasible for intended Army operations
Rotary Wing, II-8C	• Reliability factor estimated low • Hazard in RPV colliding with helo rotor (personnel safety and equipment damage) • Cost of helo platform plus special land vehicle prohibitive
• Brush Attenuator, II-9	• Mechanical feasibility of concept in question • Relatively large visual signature • Appears to be difficult to adapt

TABLE 8. TEN CONCEPTS SELECTED FOR PHASE II STUDY

		A	B	C	D
GROUP I SURFACE IMPACT	I-1 RUNWAY				
	I-2 PARACHUTE	NONGLIDING, GLIDING			
	I-3 RETRO ROCKET	RETRO-ROCKET			
	I-4 STOWED ROTOR				
	I-5 SPIN RECOVERY				
GROUP II ABOVE-SURFACE-RECOVERY	II-1 CAPTURE NET		TRAVELING	TRAVELING + I.P.	INFLATABLE FRAME
	II-2 INCLINED RAMP				
	II-3 ROTARY (CAROUSEL)	ROTARY			
	II-4 PARACHUTE		WINCH-DOWN		IN-FLIGHT HOOK-UP
	II-5 AERIAL TRACK				
	II-6 'U' CONTROL				
	II-7 ARRESTING WIRES	HIGH WIRE TRAPEZE	WIRE + I.P.		
	II-8 TETHERED AERIAL				
	II-9 BRUSH ATTENUATOR				

9.0 PHASE II RECOVERY CONCEPT STUDIES

The end product of Phase II Final Concept Selection, is to select one to three Mini-RPV recovery concepts from the group of ten concepts carried over from Phase I. The one to three concepts selected will then be carried over to Phase III for further study and evaluation for the purpose of arriving at a preferred system. The final sub-task of Phase II is to establish an evaluation procedure which numerically weighs and ranks the ten candidate recovery systems against an overall set of criteria including:

1. Accommodation by Mini-RPV.
2. Adaptability to field employment.
3. Serviceableness of recovery operations.
4. Suitability of subdivisional Army integration.
5. Acceptable cost and risk.

The studies of Phase II generally emphasize the physical aspects of field deployment of the ten candidate recovery systems carried over from Phase I. However in some instancies, additional analysis is done in the manner of Phase I investigations where it was felt that such work was needed to implement the intent of Phase II.

9.1 Parachute

9.1.1 Introduction. The parachute concepts included in Phase I under Group (I), Surface Impact, are: nongliding and gliding chutes, both included under Concept I-2A.

As noted in subsection 7.2.3 c, the hi-glide chute category is not carried over to Phase II for the purpose of surface-impact recovery.

The hi-glide chute is investigated in subsection 9.5 under Group II, Above-Surface Recovery.

9.1.2 Nongliding Chutes, Concept I-2A

a. General

The nongliding parachute was reviewed in Phase I and by virtue of its record as an established recovery concept and its general compatibility with the tactical environment, it is carried over for further study for the Mini-RPV recovery operation.

The problem now is to identify typical parameters suited to the Mini-RPV recovery requirements and to establish approximate size and weight characteristics of the airborne equipment involved.

b. Analysis Parachute Sizing

Assuming a rate of descent of 20 feet/second at ground impact as a design condition, representative diameters, for the solid textile type circular canopies, based on a C_{DO}= 0.75 are tabulated below for 120- and 200-pound class RPVs at 4000 feet altitude, 95°F. Rates of descent at sea level static conditions would be about 10 percent less:

RPV Class	Chute Dia, ft.
120 lb	23.1
200 lb	29.8

Trade-off studies in some detail would be required to optimize weight, packed volume, flight behavior (oscillations, etc.), and cost factors as a basis for selection of a specific type of chute.

Weights

Parachute weight information for Mini-RPV applications is scarce. Table 9 presents data gleaned from Reference 14 and one actual Mini-RPV interim chute for the Navy/TRA STAR (Model 262) Mini-RPV.

A computer scan of the parachute data bank at AFFDL, (Reference 30), bounded by a suspended weight of 300

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30. Deweese, J. H. PARACHUTE CANOPY WEIGHT DATA, AFFDL, Wright Patterson AFB, Ohio, 15 December 1976.

pounds maximum, produced ten chutes that would be within the diameter range of interest (about 22 to 30 feet). A second bounding limit of 10.5 pounds weight narrows the field to three chutes. One of these matches item 1 of Table 9. The remaining three are:

	DIA	WT	UNIT/WT, LB/FT:
Conical	24	6.2	0.0137
Personnel	29.5	10.5	0.0154
Guide surface	24	1.2	0.0159

The above weights include canopy and suspension lines only. Possible reductions in this weight of 10 to 12 percent is estimated by using Kevlar in place of Nylon for suspension lines.

The remaining items that are chargeable to the parachute assembly for a Mini-RPV include: a pilot or extraction chute, bridle, bag, and risers. This group of ancillary items is estimated to increase the basic canopy/suspension line weight by about 20 percent for the chute sizes applicable to the 120- and the 200-pound class RPVs. The percent variation of the ancillary items is probably due to some of these items bottoming out analogous to minimum gages in structural applications.

Based on the limited and somewhat speculative weight information discussed above, installed weights are computed assuming that the chute with the lightest unit weight (item 2, Table 9) relates to the relatively low deployment speeds of the subject RPV.

	RPV CLASS	
	120-lb	200-lb
Chute Dia, ft	23.1	29.8
Area, ft	417.3	695.5
Unit Wt, lb/ft	0.0133	0.0133
Basic Wt, lb	5.6	9.3
Ancillary items (weight factor)	1.20	1.20
Installed Wt, lb.	6.7	11.1

The use of Kevlar suspension lines would reduce the installed weights by about 8 percent.

The additional weight items would include a minimum of chute release system triggered by ground impact, cover doors and the command and control items required for

TABLE 9. TYPICAL WEIGHTS, CIRCULAR CHUTES

	DIAMETER ft	AREA ft^2	WEIGHT lb	UNIT WEIGHT lb/ft^2
Solid Flat				
1	24	452	10	0.022
2	24	452	6	0.0133
3	28	617	9.3	0.0151
4	30	707	11.1	0.0157 (1)
Tri Conical				
5	22	380	5.3	0.0139
Light Weight Cross (2)				
6	24	320 (3)	3.0	0.0094

(1) Interim Chute Navy/Star RPV
(2) Designed for 80 lb RPV
(3) Actual Flat Surface Area

chute deployment.

Packed Volume

Packed volumes for the chutes defined above are estimated as follows:

	RPV CLASS		
	120-lb	200-lb	Density
Chute Wt, lb	6.7	11.1	
Pressure pack Vol, ft^3	0.149	0.246	45 lb/ft^3
Loose Pack Vol, ft^3	0.223	0.370	30 lb/ft^3

Ground Support Equipment

The major ground support equipment required for the parachute recovery concept would be a means of retrieving the RPV after it has landed. This could be accomplished by means of a sling and a hand-powered hoist attached to one of the land vehicles already assigned to the RPV Army field section.

Logistic supplies would include prepacked parachutes and recovery system related spare parts.

c. Conclusions

It appears that a concerted effort will be required to design parachutes specifically for Mini-RPV recovery applications. Beginning with the peculiar design criteria involved, the effort should include analysis of all the chute assembly components with a view to optimizing weights by appropriate materials selections and innovative detail design.

However, as the state of the art now stands, improvised chute installations of about 8 to 10 percent of the RPV gross weight have been designed with off-the-shelf components. (Ref. subsection 7.2.2 a)

Very much a part of an acceptable chute recovery installation is that it be made a part of the systems approach applied to the RPV in the early stages of design.

9.2 Vectored Retro Rocket, Concept I-3A

9.2.1 General. The vectored retro rocket recovery concept previously discussed under Phase I, subsection 7.3, is attractive from the point of view of being a totally airborne system which portends less ground equipment, which aids mobility.

In this subsection, the retro rocket application is expanded further to gain additional understanding of its pros and cons as a Phase II candidate.

9.2.2 Analysis

Flight Path Considerations

The height at which the rocket would have to be fired, and the distances required to decelerate along a 6-degree flight path were shown in Phase I, Table 6. These data are summarized below for the 120-pound class RPV.

n, (g)	ℓ_r(ft)	h_1
3	37	3.9
6	18	1.9
12	9	1.0

Figure 77 shows that the 50-knot design speed, corresponds to an angle of attack of 7.5 degrees for the 4,000 foot, 95°F condition. Thus, the rocket thrust vector, F, would have to be angled 7.5 degrees with respect to the RPV's horizontal reference plane to meet the design condition. The 6-degree flight path can be maintained by applying power to match the trimmed 7.5 degrees angle of attack.

For a sea level standard atmospheric environment, the 7.5 degrees angle would correspond to a 45-knot flight speed. Thus if the rocket is designed to fire at a height based on 50 knots, the RPV would decelerate to zero before ground contact when approaching at 45 knots, causing the RPV to free-fall a short distance. Likewise, lower speeds at colder ambient conditions would further shorten the deceleration distances. However, in consideration of the small values of the heights, h_1, involved, the atmospheric conditions alone would probably have a negligible effect on the safety of the RPV as long as the design thrust vector angle, 7.5 degrees in this case, is maintained with respect to the flight path.

Another set of variables of more consequence where the thrust angle is fixed is due to velocity perturbations along the flight path. In this case, the desired flight path of 6 degrees corresponds to different angles of attack. For example, (Figure 77), a 5-knot increase in velocity for the 4000-foot, 95°F condition corresponds to an angle of attack of 6.2 degrees, and a 5-knot decrease to 9.8 degrees. Thus the rocket thrust line would be pointed 7.5 - 6.2 = 1.3 degrees too low for the higher velocity and 9.8 - 7.5 = 2.2 degrees too high for the lower velocity.

The effects of these are illustrated in Figure 78.

Thrust Misalignment

The nominal effects of rocket thrust line misalignment within the RPV are assessed by assuming a 0.10-inch offset between the thrust line and the C.G. in the plane of symmetry (Figure 79). Computations are made for the 120-pound RPV only. Using a rotational inertia value of 9 slug/ft^2 about the pitch axis, numbers are computated as shown below.

Linear Deceleration Factor, n, g	Angular Acceleration, rad/sec	Angular Velocity, rad/sec	Time, t, sec (1)	Angular Displacement, θ, deg
3	0.333	0.292	0.875	7.30
6	0.666	0.292	0.437	3.64
12	1.333	0.292	0.219	1.83

(1) Ref Table 6.

In the above numbers we see further incentive for using higher linear deceleration factors for "getting-it-over-with" before very much can go wrong. The angular displacement, θ, due to thrust misalignment, coupled with flight path errors could conceivably create unacceptable deviations at the lower load factors.

The above assumptions of 0.1-inch misalignment is very optimistic in view of the known C.G. travel envelopes for the types of RPVs analyzed in this study.

Wind Conditions

Superimposed on the above sources of error would be wind

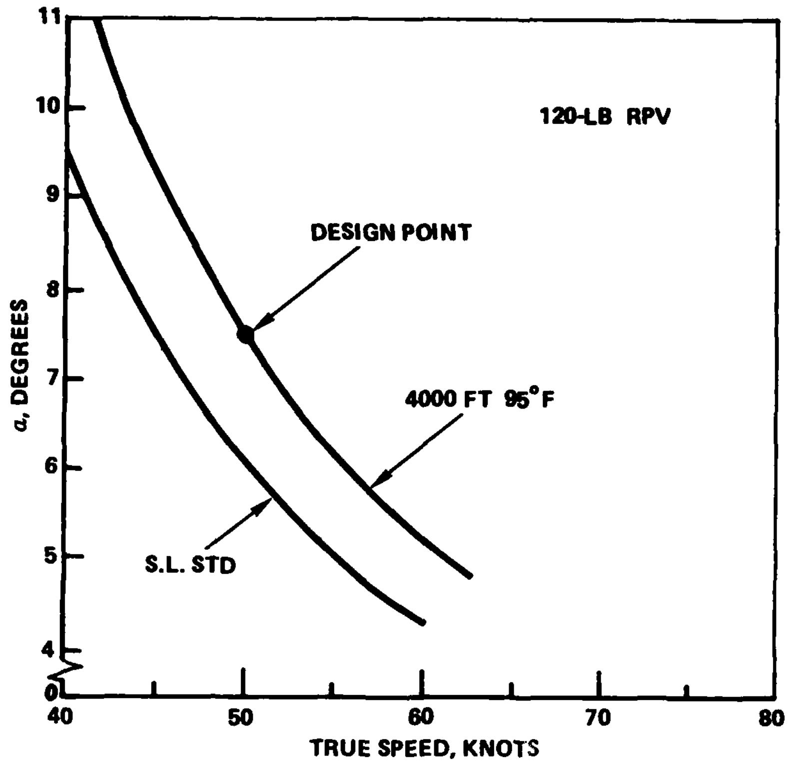


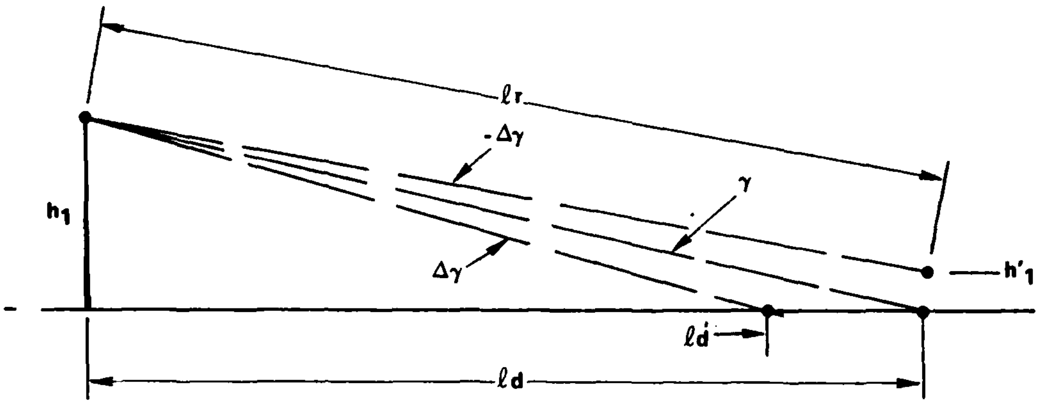
Figure 77. Angle of Attack Versus Approach Speed

conditions. In the case of no correction made for a head wind, the RPV would maintain the same attitude with respect to the earth but would be descending along a steeper flight path angle than desired. Attempting to correct for the wind by increasing airspeed so that the RPV would maintain the proper flight path angle would amount to flying at an angle of attack lower than desired.

Rocket Data

Estimates of the retro rocket characteristics required for the 120- and 200-pound class RPVs are shown in Table 10. The assumption is made that small, special-purpose solid propellant rockets of this type would have to be designed for low cost. Therefore, performance characteristics are based on a relatively low specific impulse (I_{SP}) of 210 seconds.

It is interesting to note that with constant impulse (Ft) the propellant weight and rocket weights are constant.



+Δγ	ℓ'd/ℓd
1°	0.856
2°	0.740

+Δγ	h'1/h1
1°	0.166
2°	0.332

-Δγ: ROCKET THRUST LOW
+Δγ: ROCKET THRUST HIGH

Figure 78. Effects of Flight Path Deviation

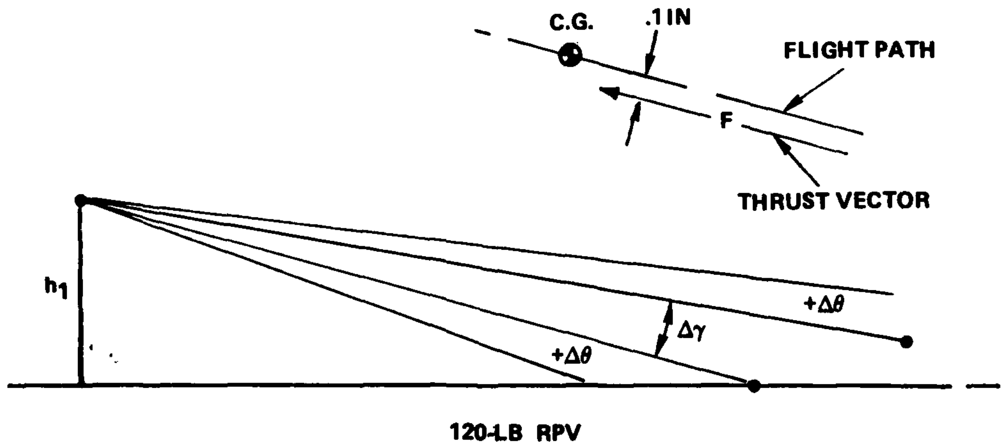


Figure 79. Effects of Rocket Thrust Misalignment

TABLE 10. RETRO ROCKET DATA

η	w_f lb/sec	t sec	w_p lb	MASS FRACTION	w_r lb
120-LB RPV					
3	1.7	0.88	1.5	0.6	2.5
6	3.4	0.44	1.5	0.6	2.5
12	6.9	0.22	1.5	0.6	2.5
200-LB RPV					
3	2.9	1.36	3.89	0.6	6.5
6	5.7	0.68	3.89	0.6	6.5
12	11.4	0.34	3.89	0.6	6.5

The percentage weight of the bare rockets in terms of gross weight would be higher for the 200-pound class RPV at about 3.2 percent as compared to 2.1 percent for the 120-pound RPV.

An estimate of rocket sizes is made by assuming a density of 100 pounds/feet and a length/diameter ratio of 5. These assumptions result in the cylinder dimensions:

	120-lb RPV	200-lb RPV
ℓ, in.	11.1	15.3
d, in.	2.2	3.1

The above dimensions are offered as average package size indications.

Retro Rocket Location Options

In Figure 80 (a) a single retro rocket is shown in the plane of symmetry of the Aquila-type RPV, the basis for the analysis in paragraphs above. This arrangement would presumably interfere with the RPV's payload, and perhaps equipment now located in, or planned for, the nose compartment. It is highly probable that such interference problems would be typical for Mini-RPVs in general.

An alternate arrangement shown in Figure 80 (b), shows a main retarding rocket on the centerline of the vehicle and a smaller rocket supplying vertical thrust at the C.G. of the RPV.

Should the placement of retro rockets in the plane of symmetry be found unacceptable for space priority and/or other reasons, an alternative solution would be to use wing located rockets in pairs. This alternative would probably aggravate thrust misalignment problems.

Increasing the number of rockets would undoubtedly increase the unit weight/pound of thrust aboard the RPV. Speculation in this regard is that for all practical purposes the weight of the main retarding rocket of Figure 80 (b) would be about the same as the single rocket canted 6 degrees shown in Figure 80 (a). Thus the weight of the vertical rocket at the C.G. is essentially additive. Further multiplicity of rockets would compound the weight problem.

Target Window

Relying on a stinger (or a radar altimeter) to initiate rocket firing implies errors due to false reading caused by sudden changes in terrain contour. Moderate directional errors could be tolerated since the intent of the system is only to get down from a known height, not necessarily on a fixed spot on the ground. Thus the main functions of the terminal guidance system is to maintain pitch attitude and speed for a given flight path.

Conclusions

The above cursory analysis indicates that for a simple, fixed retro rocket system for recovering an RPV, random accumulations of individual errors due to flight path deviations, thrust misalignment, and false reading for the proper height to fire the rocket could conceivably add up to unacceptable performance variations. Part of accepting a certain level of error is the building in of more ruggedness in the RPV and/or impact attenuation provisions.

Technology is available to solve all the apparent problems for the retro rocket concept. But the ultimate level of sophistication, and development costs and time, are believed to be beyond the intent of a Mini-RPV recovery system.

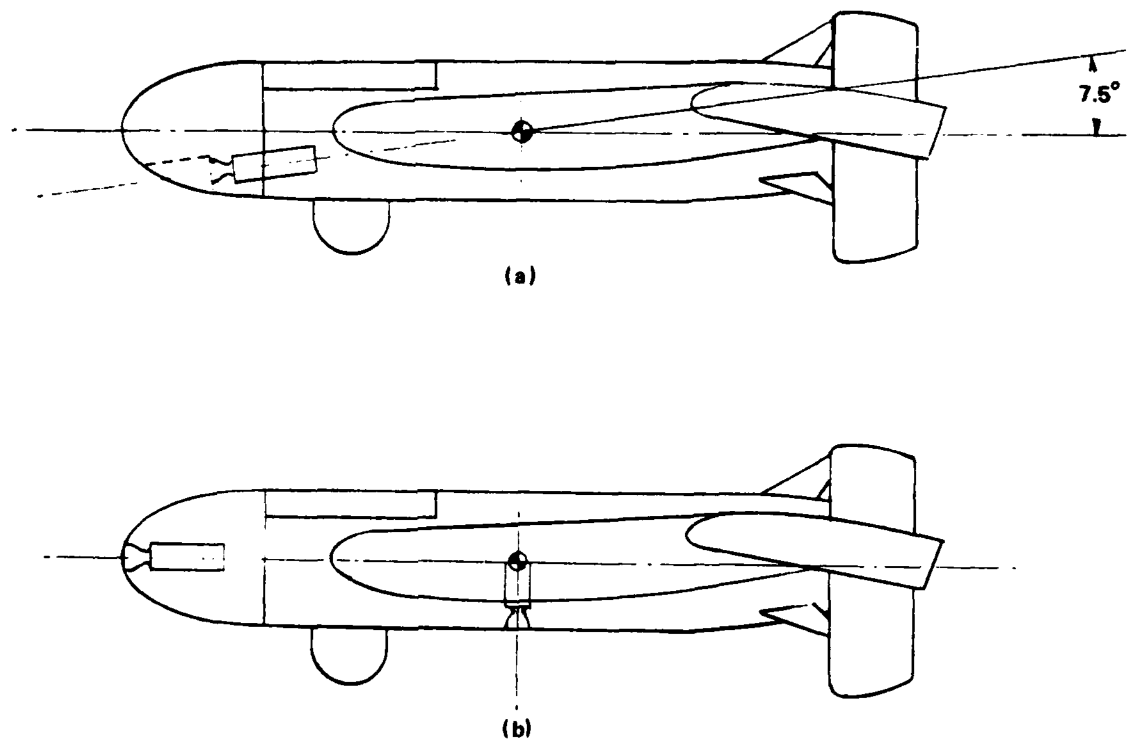


Figure 80. Retro Rocket Location Options

Problems for the 200-pound class RPV would be similar except of a higher order.

For either type RPV, the inevitable contingency for growth in gross weight would have to be accounted for in the initial design of the retro rockets.

Recovery ground support equipment for the retro rocket RPV would be minimal since the system is entirely airborne.

In summary, it appears that the retro rocket's most attractive features - minimal ground equipment would be outweighed by the technical risks involved or the increases in system sophistication, and consequently the development time and cost required to solve the apparent problems.

9.3 Capture Net, Concept II-1

9.3.1 Introduction.

The capture net concepts discussed in this section are:

9.3.2 Traveling Net, Concept II-1B

9.3.3 Traveling Net Plus Impact Platform, Concept II-1C

9.3.4 Inflatable Frame/Net, Concept II-1D

9.3.2 Traveling Net, Concept II-1B

a. General

The traveling net concept initially reviewed in subsection 7.6.3 is shown in Figure 81 as a mobile configuration mounted on two M-135 trucks. The net system support structure folds over the top of the truck for transport as shown by the dashed lines.

The dimensions shown on Figure 81 are approximate, but representative of a system designed to handle the 200-pound class RPV.

At the recovery site, the truck with the net would be positioned first, the diagonal braces put in place, and the net would then be rigged. The truck with the third, or single, stanchion would then be maneuvered into position and the rigging completed.

If the same type energy absorbers (water turbines) as shown in Figures 29 and 30 are to be used for the truck-mounted installation, they could no longer be secured to the ground.

For this situation, the energy absorbers could be placed on the truck supporting the single stanchion with long lines leading back to the truck with the net installation.

An alternate arrangement employing a multi-wire/sheave system similar in principle to that used on aircraft carrier arresting gear systems is indicated in Figure 81. This arrangement would require an energy absorber with a much shorter stroke.

To reposition the entire rig to accommodate a shift in wind direction, the foot pads would have to be raised and the lines between the trucks would have to be let down with considerable droop by the rigging winch. For the purpose of repositioning, it appears that the single rigging line between the winch and the apex of the run-out cables could include extra length (cable available longer than the 55-foot dimension) to aid maneuvering the truck with the single stanchion to a new position.

Retrieval of the RPV after the recovery sequence is completed could be accomplished by lowering the net with the RPV in it to the ground or other surface by means of the rigging winch. The RPV could then be transferred to its handling fixture. Some form of small hand operated hoist would be preferable for lifting the RPV onto the handling fixture.

b. Conclusions

The truck-mounted mobile rig for the traveling net recovery system appears to involve only moderate engineering and manufacturing problems.

It is surmised that the system could be rigged and ready for operation well within the time (1 hour) and personnel (4 men) allocated and conversely could be dismantled in 30 minutes.

The configuration of the system is such that it could be installed on moderately sloping ground and with the trucks at slightly different elevations with respect to each other.

The most difficult operational factor to assess at this stage is whether or not this particular rig could be repositioned in 5 minutes to accommodate a wind shift. It appears that the actual amount of angular change would not have a significant effect on the total time to get back to the ready condition.

9.3.3 Traveling Net Plus Impact Platform, Concept II-C

a. General

The traveling net plus impact platform concepts described in subsection 7.6.4 are presented in this section as: (1) a mobile configuration employing the M-135 trucks for the ribbon (or tape) type impact platform (Figure 82) and, (2) a configuration employing one M-135 truck for the air mat-type platform (Figure 83).

The net installation truck for either the configuration with the ribbon (tape) type impact platform or the inflatable air mat type (Figure 83) would be basically the same. However, for the ribbon type platform, a horizontal bar, or tube spanning the distance between stanchions would have to be placed near the bottom edge of the net to provide for attaching the ribbons.

The outer end of the ribbon type platform would be supported by the second M-135 truck. One means of attaching the ribbons would be to employ a horizontal tube running lengthwise of the truck mounted on pivoting arms pinned to fitting at the extremities of the truck (Figure 82). The tube would be of thinwall construction and fairly large (about 1 foot) in diameter. The tube would also serve as a hand actuated reel to wind the ribbons on for stowage. The tube with the ribbons reeled in would rest on the top of the truck for transport as shown in Figure 82.

The air mat-type recovery system would require less precision to erect, since the truck and the air mat are relatively independent of each other in so far as rigging is concerned.

The air mat's alignment could be adjusted by hand by sliding it on the ground as needed. Low density mats (about 0.023 lb/ft^3) such as the one shown in Figure 34 would require some form of tie-down. Since stakes are

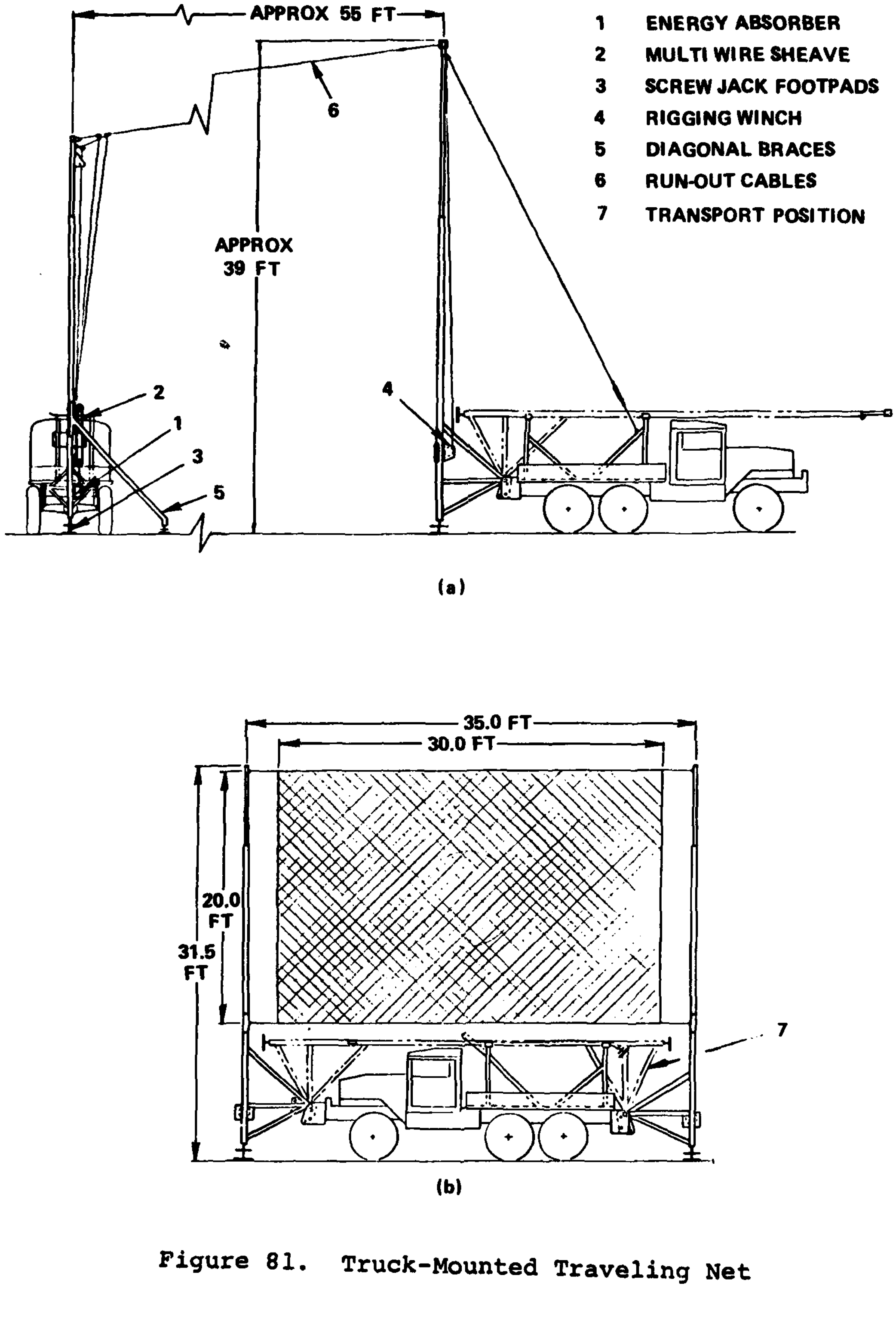


Figure 81. Truck-Mounted Traveling Net

undesirable, weights of some type would be an alternative.

To reposition the ribbon-type impact platform would require raising the foot pads and unreeling the outer end of the platform to provide enough slack to safely maneuver the trucks. Angular position changes could then be made by backing one truck and moving the other forward such that they are more or less circling a point midway between them. The system would then be rigged as required (foot pads adjusted and ribbons tightened).

To reposition the air mat system would be less exacting in that the one truck involved can be maneuvered independently of the air mat. If repositioning involves considerable distances within the recovery area, the mat may have to be deflated for transport. However, for accommodating wind direction changes the mat could conceivably be more or less rotated about its own center by sliding it.

The best methods of retrieving the RPV after the recovery sequence is completed for either the ribbon- or the air-mat type platforms would presumably have to be determined from test experience. In the case of the ribbon-type system, it can be speculated that the ribbon platform, with the RPV still in the net, would be lowered onto a handling fixture for the RPV. The upper part of the net could then be folded back off the RPV after releasing the upper lines of the net. It would then be a matter of working both the remaining net ribbons and the platform off the RPV, leaving it supported by the handling fixture.

An alternative would be to lift the RPV by means of a jeep (or other vehicle)-mounted hoist after the net has been folded back.

Reaching an RPV sitting in the middle of a low-density air mat for retrieval purposes would seem to be more difficult than for the ribbon type platform. The RPV, while still in the net, could be dragged to an edge of the mat where it could be hoisted or lifted onto a handling fixture. Deflating the mat, of course, provides a way to get at the RPV. However, the time to reinflate would have to be considered if multiple recoveries are to be made within a short time.

b. Conclusions

As with the traveling net, subsection 9.3.2, the two

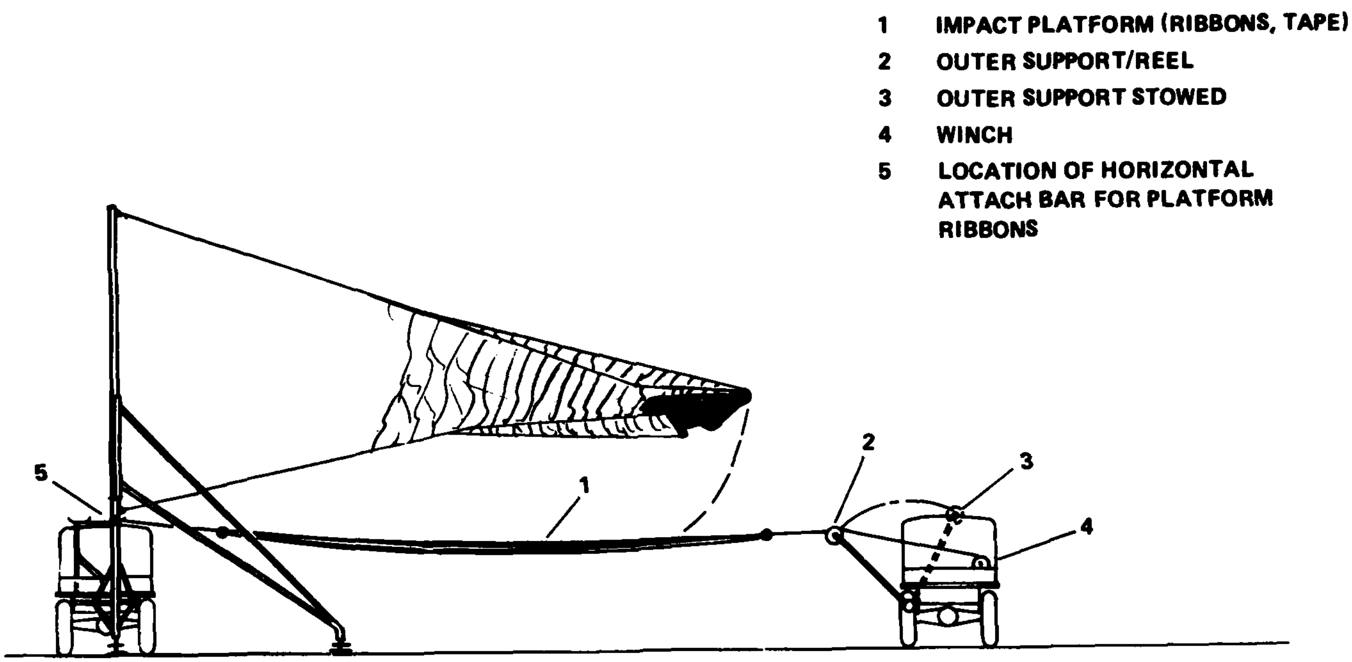


Figure 82. Truck-Mounted Traveling Net Plus I.P. (Ribbon, Tape)

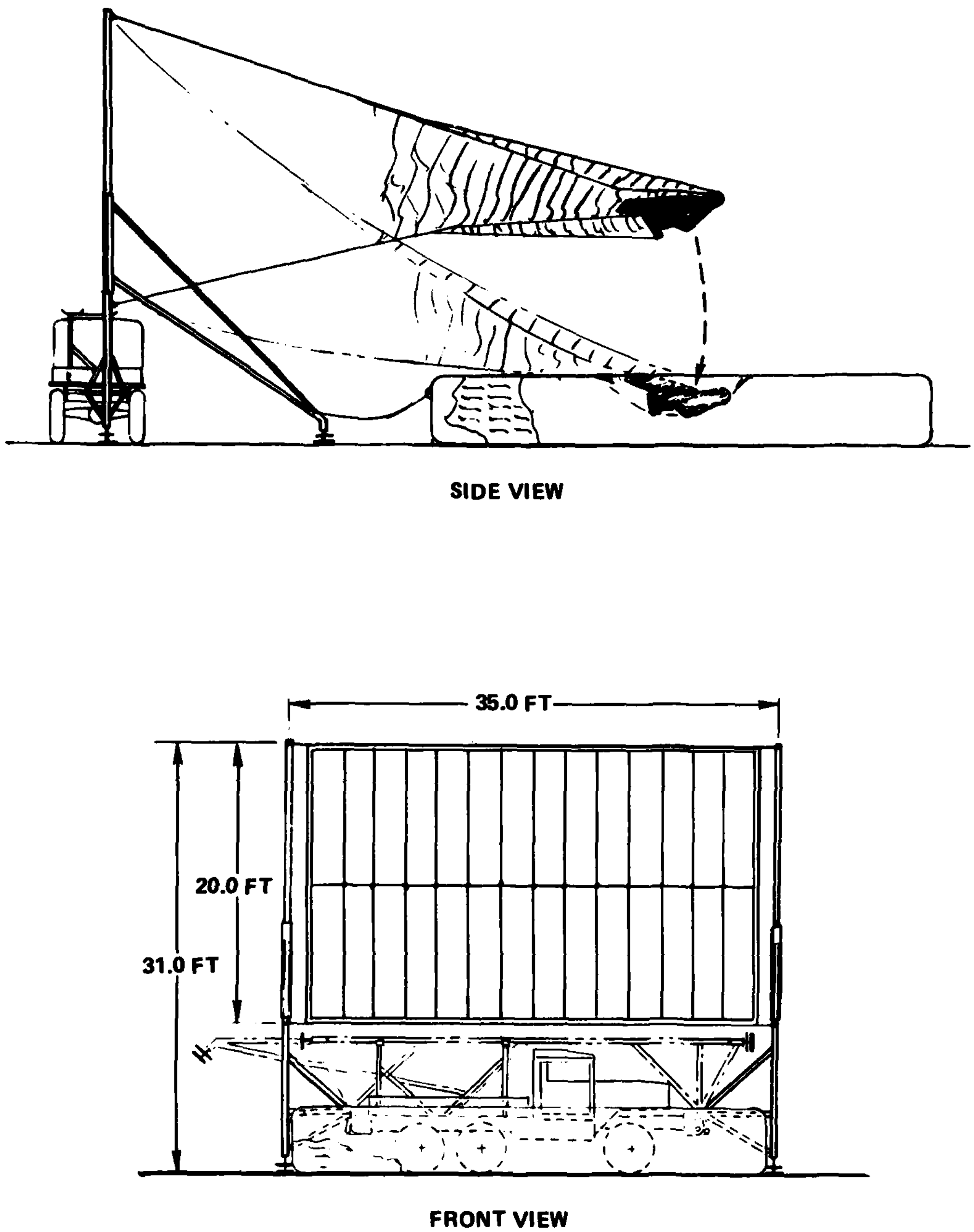


Figure 83. Truck-Mounted Traveling Net Plus I.P. (Air Bag)

traveling net plus impact platform recovery concepts discussed above appear to involve only moderate engineering and manufacturing problems.

Either the ribbon-type platform or the air mat-type system could be erected within the desired time and personnel limits.

Both of the recovery systems would tolerate moderately sloping ground and elevation anomalies at the recovery site.

Further study would be required to determine whether the recovery system with the ribbon-type platform could be repositioned and rerigged within 5 minutes to accommodate changes in wind direction.

It appears that the air mat-type could be repositioned in 5 minutes, with reservations if the mat has to be deflated.

9.3.4 Inflatable Frame/Net, Concept II-1D

a. General

The inflatable frame/net recovery concept was selected (see Section 8.0) as one of the ten concepts to be carried over to Phase II based on the data available at the time of selection.

Further work on the concept, summarized in subsection 7.6.5 leads to the conclusion that the concept would not be suitable for deployment in Army Tactical environments.

Therefore, no further studies will be conducted for the Inflatable Frame/Net Concept.

9.4 Rotary (Carousel), Concept II-3A

9.4.1 General The rotary, or carousel, concept discussed in subsection 7.8 is shown in Figures 84 and 85 as a truck-mounted configuration.

Practical aspects of truck mounting indicate that the minimum radial arm length of about 18.8 feet corresponding to a limit of 12g (see Figure 44) is too short. In Figure 84 a fixed radial arm is shown set at 21 feet to provide clearance from the truck for the RPV in retrieval position. The total radial arm to the C.G. of the RPV would be 21+5+6 = 32 feet, and the maximum centrifugal load factor at engagement would be

$$\begin{aligned} n &= V^2/gr \\ &= (50 \times 1.69)^2/32.2 \times 32 \\ &= 6.9 \end{aligned} \tag{37}$$

Reducing the centrifugal load factor from 12 to 6.9 g would probably have some favorable aspects. On the other hand, as mentioned in subsection 7.8, the inertia of the longer fixed arms could also create objectionable dynamic problems. The fixed arm could, of course, be shortened by increasing the height of the central stanchion, letting the RPV be suspended above the truck in the retrieval position. Shortening the radial arm by this means would not necessarily help the overall effects of the inherent dynamic unbalance or the rotating system on the support structure and truck.

An apparent cure, at the expense of complexity, for the dynamic unbalance problem would be to place a weight on the fixed radial arm to the opposite side as shown by the dotted lines in Figure 84. An infinite number of balance weight/arm combinations would provide balance for the centrifugal force created by the RPV. However, the rotational inertia of the balance weight would greatly aggravate the problems associated with the dynamic forces related to engagement and would accelerate the radial arm from zero to a relatively high tangential velocity in a very short time interval.

A truck-mounted rig is shown in Figure 85 for the larger 200-pound RPV with the extended cable required to limit the centrifugal load factor to 12 g. Dynamic problems for this configuration would be similar but of higher order than those for the 120-pound RPV.

9.4.2 Conclusions. The rotary (carousel) concept could conceivably be made a truly one-truck mobile system with minimum constraints as to repositioning and accommodating wind shift conditions within the desired 5-minute time interval.

The major disadvantage of the system appears to be the high

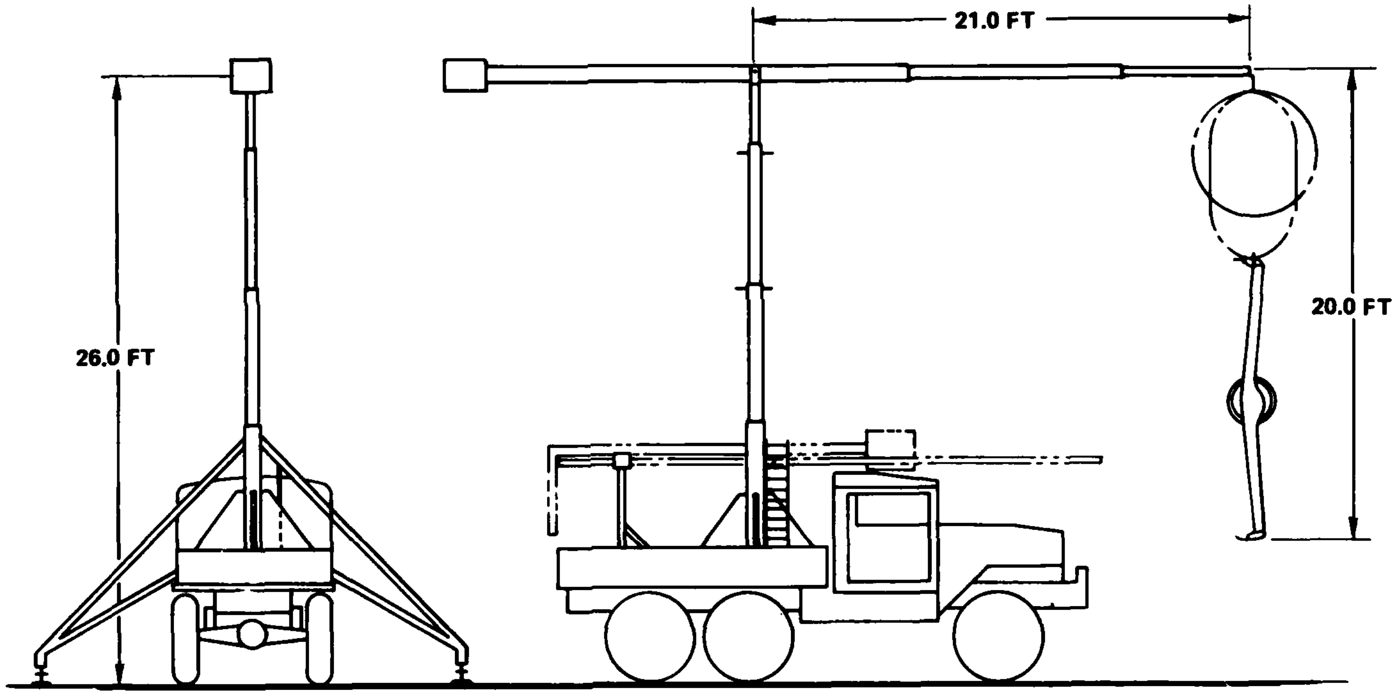


Figure 84. Truck-Mounted Rotary (Carousel), 120-Pound RPV

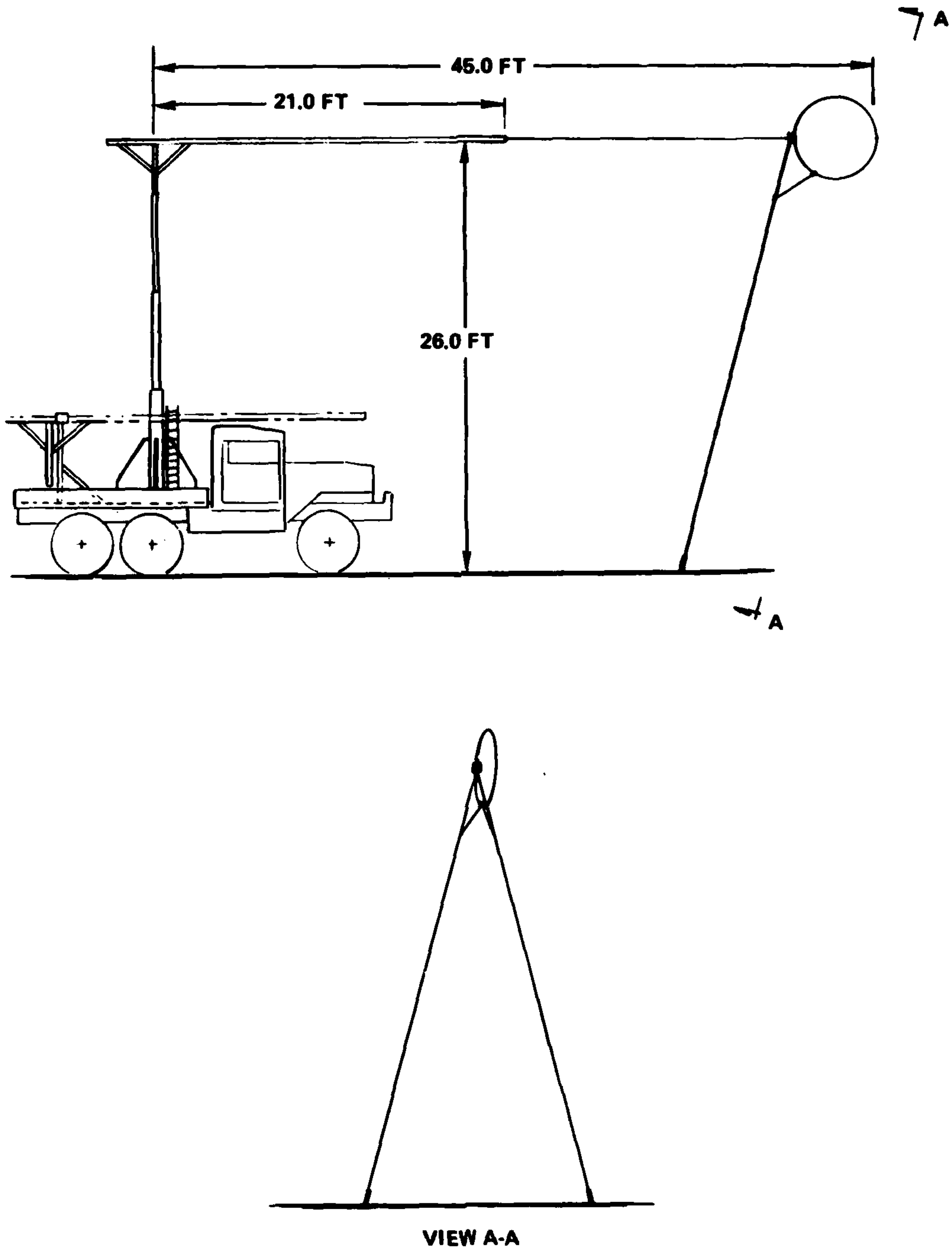


Figure 85. Truck-Mounted Rotary (Carousel), 200-Pound RPV

technical risks involved in: (1) achieving proper engagement of the RPV (Ref. subsection 7.8), and (2) suppressing high transient loads that would result from the rotational inertia of the rotating arm system.

9.5 Parachute, Concept II-4

9.5.1 Introduction. The two parachute concepts in the Group II, Above-Surface-Recovery category that were carried over from Phase I for further study are discussed in this section. The concepts are:

9.5.2 Winch-Down, Concept II-4B

9.5.3 In-Flight Hook-Up, Concept II-4D

9.5.2 Winch-Down, Concept II-4B

a. General

The parachute winch-down concept carried over (subsection 7.9.3) is shown in Figure 86 mounted on two trucks as it would appear in the recovery area.

The two stanchions that support the pick-up wire at the entry of the recovery area could be of the telescoping type made of light material such as fiberglass. The wire could be restrained by smooth spikes located near the top of the stanchions. The spikes could be angled upward and inward slightly to keep the wire from dropping off prematurely. The loads imposed on the stanchions as the cable leaves the spikes would be very small. The stanchions could be mounted on a small land vehicle such as a jeep instead of a M-135 truck. With the stanchions mounted in an angled out configuration on the small vehicle, the distance between stanchions at the top could be set, for example, 35 feet apart.

The winch-down truck, an M-135 vehicle, is shown in Figure 86 in two configurations for RPV recovery. In the lower right hand corner of the figure a telescoping tube-type shock attenuator is shown. The tube assembly would be mounted so that it could be tilted and/or swiveled to maintain close alignment with the cable being reeled in. The cable would pass through the tube,

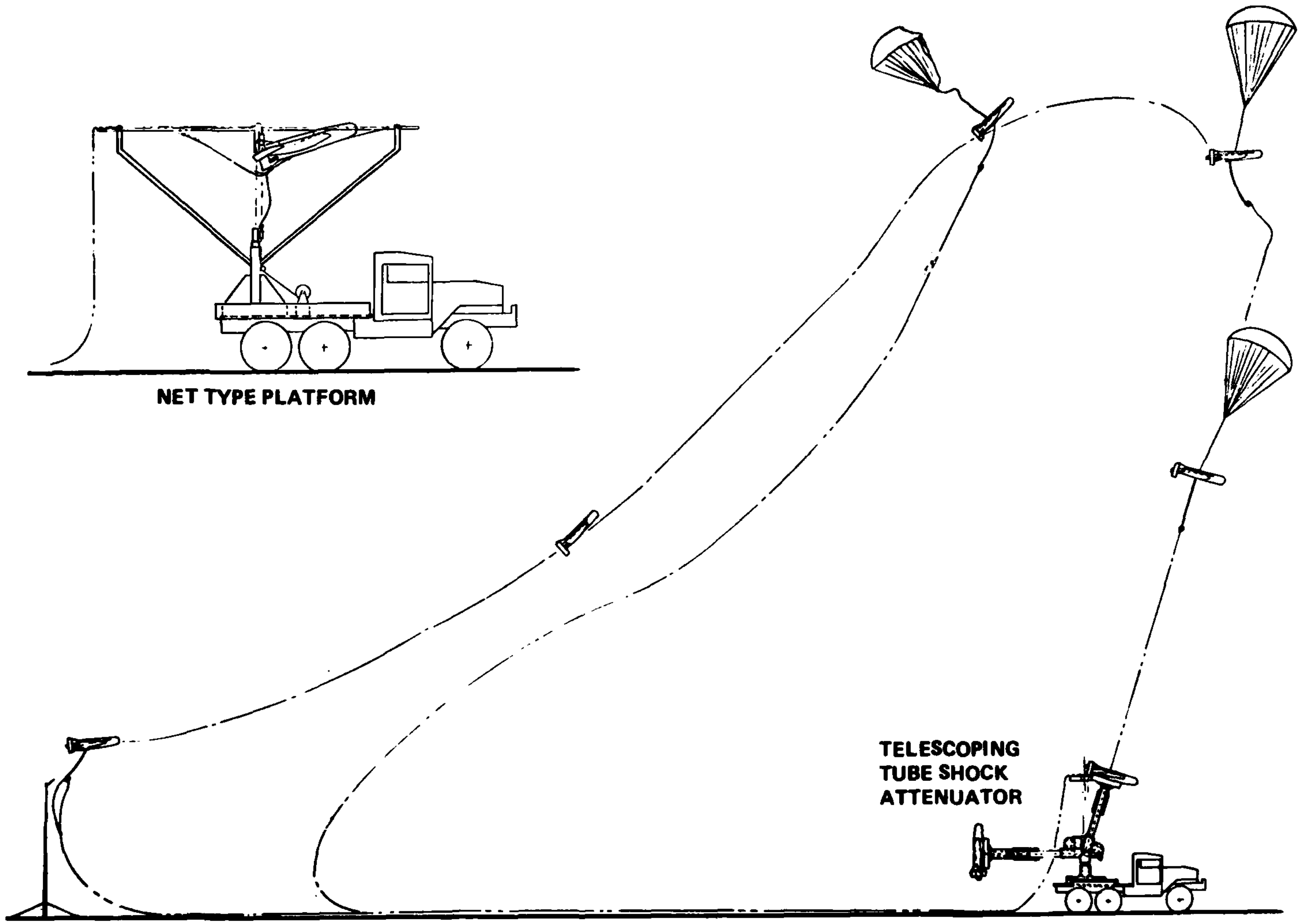


Figure 86. Truck-Mounted Parachute Winch-Down

and over a pulley to a motor-operated winch mounted on the outside of the tube near its pivot point. The tube would be long enough, and big enough in diameter to swallow the RPV's trailing hook. The RPV would initially impact a soft pad of foam rubber or similar material located at the upper end of the tube. The major part of the energy would be absorbed by two air/oil type struts constructed similar in principle, but in a much less expensive manner, than shock struts for wheeled aircraft. The stroke distance for the struts would have to be determined by the reel-in velocities for the higher tilt angle limits anticipated for the winch-down concept. However, for speculation purposes the stroke (neglecting the effect of the soft impact pad) for a 22-foot/second velocity would be 0.68 feet for 12 g; 1.50 feet for 6 g; and 3.75 feet for 3 g considering both the potential and kinetic energy involved.

The telescoping tube assembly could be tilted back for retrieval of the RPV as shown, and after removal of the impact pad, could be folded over the top of the truck for transport. An inset in the upper left hand corner of Figure 86 shows a horizontal net-type platform configured to fulfill the intent of the concept as originally presented. In this case the net height above the truck would have to be sufficient to provide for the RPV's hook and the longer stroke distances needed to absorb energy with the net than for the more efficient air/oil type energy absorbers. Retrieval of the RPV, properly secured to the net, could be accomplished in a manner similar to the telescoping tube arrangement by tilting the net frame.

b. Conclusions

From the field deployment point of view, the winch-down concept would apparently be quite adaptable to varying terrain conditions and could be erected and dismantled in relatively short periods of time.

For adjusting to wind shift conditions the smaller vehicle with the wire pick-up stanchions could be driven to a new position leaving the M-135 truck to be maneuvered for direction changes near its original location. For changing position, it would probably be necessary to reel in the cable to the M-135 recovery truck, drive the smaller vehicle to a point close to the truck, then drive in a radial direction, pulling the cable to the new location for the small vehicle.

The major disadvantages of the system, noted in subsection 7.9.3 c, related to airborne weight probably being higher than desired, and the effects of under and over-shooting the vertical reel-in position excessively, and of wind.

The development cost and time for the winch-down system is estimated to be moderate, provided ready solutions are available for the perceived operational problems noted above.

9.5.3 In-Flight Hook-up Concept II-D

a. General

The truck-mounted recovery rig for the in-flight hook-up shown in Figure 87 is representative of the size required for the middle class hi-glide chute ($W/S = 1.04$ pounds/foot , $V_n = 41.25$ feet/second, or 24 knots) for the 200-pound class RPV. As noted in subsection 7.9.5 b, the height allowance may be inadequate to account for the draping, or sagging of the chute after hook-up.

The system would be erected by first extending and pinning the telescoped sections of the stanchions while they are still in the stowed position on top of the truck. Then the cross arm assembly would be put in place and pinned to the stanchion. The unit could then be raised in place by a hand-powered hydraulic jack. Telescoping the cross arm would be hampered by the protruding prongs. A pinned, bolted joint in the middle of the arm would permit folding it for transport.

Although the structure of the truck-supported recovery framework would be relatively simple, careful design would be required to regulate deflections and perhaps unfavorable spring-back conditions during the recovery process. The energy level of the 200-pound RPV approaching at 24 knots is only about 1/10 of that for the traveling net, for example. However, a better indication of the actual applied loads to be expected is gained from subsection 7.9.5 b, where it is seen that the maximum centrifugal load factor near the bottom of the up-swing, is about 2.7 for the 200-pound RPV, or an applied load of 540 pounds. This load would create the maximum bending stresses in the cantilever horizontal arm and vertical stanchion. As the RPV continues swinging upward, the applied load of course decreases as the tangential velocity decreases toward zero at the top of the swing. In the interim an infinite number of combinations of bending stresses and torsion in the stanchion occur.

The various deflections of the recovery framework will absorb energy but will tend to return a very high percentage since the structure will be designed to remain in the elastic regime of the material.

So, in addition to strength considerations, the eccentrically loaded frame work would be designed for appropriate elastic characteristics.

The eccentricity could be eliminated by employing a symmetric frame using two trucks. The dimension of the horizontal member would increase somewhat to provide adequate lateral window clearances.

Either the eccentric or symmetric framework could be designed to include energy-absorbing devices as a last resort.

The truck-mounted, in-flight hook-up recovery installation of Figure 87 would be a highly mobile system that could be easily repositioned in the recovery area by lifting the foot pad on the diagonal brace for the truck.

b. Conclusions

The ground components of the in-flight hook-up recovery system would appear to meet the general requirements for tactical deployment.

The problem areas as noted in subsection 7.9.5 rest more with the airborne equipment: the development of a steering system, weight of the airborne equipment (chute plus steering), and doubtful thrust levels for chute-supported flight for the present generation of Mini-RPVs.

9.6 Arresting Wires, Concept II-7

9.6.1 Introduction. The two arresting wire concepts in the group II, Above-Surface-Recovery category carried over from Phase I for further study are discussed in this section. The concepts are:

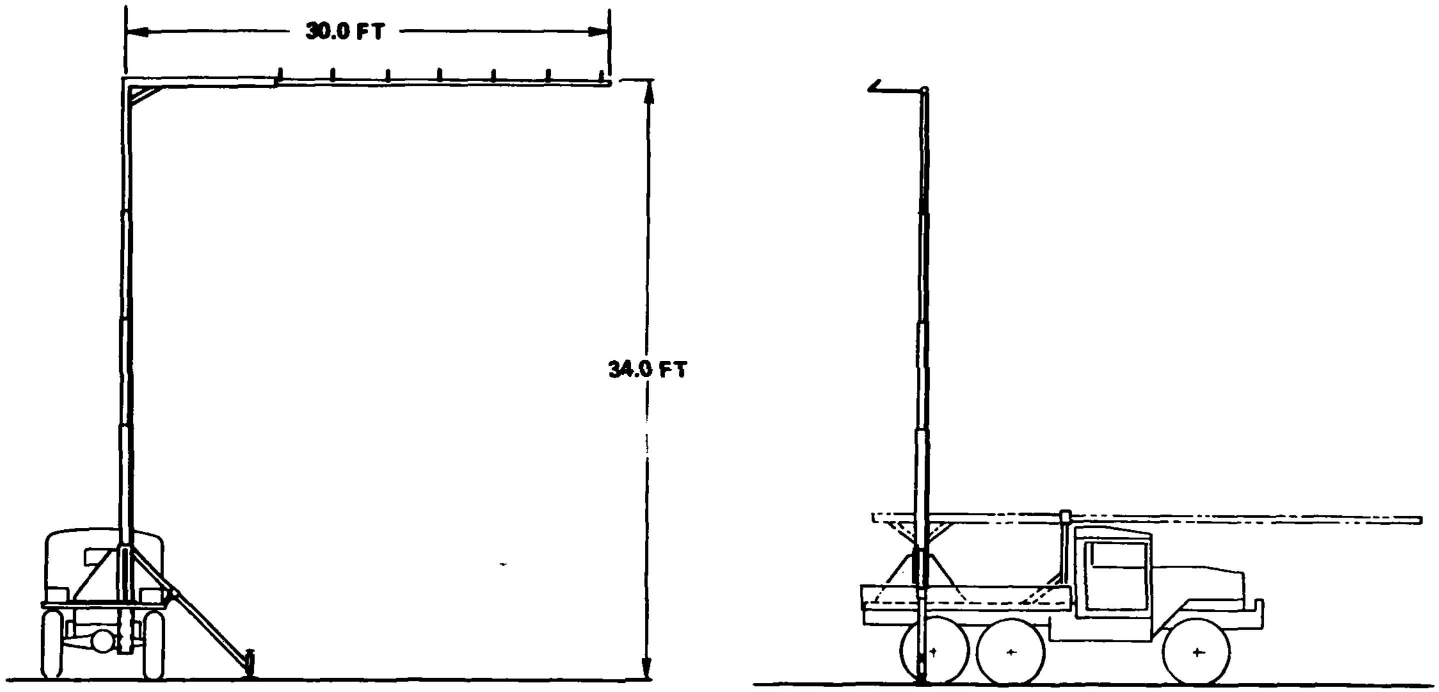


Figure 87. Truck-Mounted In-Flight Hook Up

9.6.2 High-Wire Trapeze, Concept II-7A

a. General

The high-wire trapeze recovery concept carried over from subsection 7.12.2 is shown in Figure 88 in a configuration employing two trucks for mounting and in Figure 89 for a single-truck configuration. The telescoping stanchions would fold over the top of the truck(s) for transport in much the same manner for either the two-, or one-truck configuration.

The basic mechanical configuration of the high-wire trapeze concept, consisting principally of two stanchions and a wire system leading to energy absorbers near the base of the stanchions, is relatively simple.

Water turbine-type energy absorbers, which would have to also serve as winches for resetting the line and lowering the RPV for retrieval purposes, are shown.

The stanchions for the two-truck arrangement were estimated in subsection 7.12.2 to be 47 feet high for the 200-pound RPV at 12g deceleration. Stanchions for the single truck would be about 9 feet longer, or 56 feet high. Lesser g criteria would make the stanchions correspondingly higher.

To errect the system, the telescoping sections of the stanchions would be extended and pinned, or otherwise secured, while still in the transport position. The energy absorber snubber lines would be allowed to payout as the stanchions were extended. The stanchion assemblies would then be pivoted in place by a hydraulic jack.

Retrieval would be accomplished by lowering the RPV onto a handling fixture which would be a little more difficult for the single-truck version since the RPV would have to be held away from the truck as it was being lowered.

The rather long lengths of the stanchions probably means that appreciable deflections under load will have to be accepted in the interest of moderate weight and handleability.

The amount of deflection permitted would be a subject for in-depth analysis and tests to determine if detrimental dynamic spring-back effects existed. The truck-mounted high-wire trapeze recovery system could be readily repositioned by lifting the screw-jack foot pads under the stanchions and the diagonal braces. However, traveling any appreciable distance with the stanchions erected may not be feasible.

Erecting and dismantling the high-wire system(s) are estimated to be well within the time and personnel allotment specified.

b. Conclusions

The truck-mounted high-wire trapeze recovery concepts discussed above would appear to meet the general requirements for tactical deployment, with reservations concerning the visual and perhaps other forms of detectability for the tall stanchions.

However, the height of the stanchions enhances the go-around performance of the RPV whether it be a wave-off or a missed engagement.

A major problem with the concept appears to be achieving high enough reliability of the tail hook engaging the wire when the hook is impacted at any point along its length.

Another problem area is the dynamics of a flexible stanchion system as it affects the behavior of the wire/stanchion system and the engaged RPV.

9.6.3 Wire Plus Impact Platform, Concept II-7B

a. General

The wire plus impact platform concept shown in Figures 90 and 34 using an airmat as a platform differs from the traveling net plus I.P. of Figure 83, principally in the method of capture. A wire system employing a ribbon (or tape)-type impact platform would also be similar in

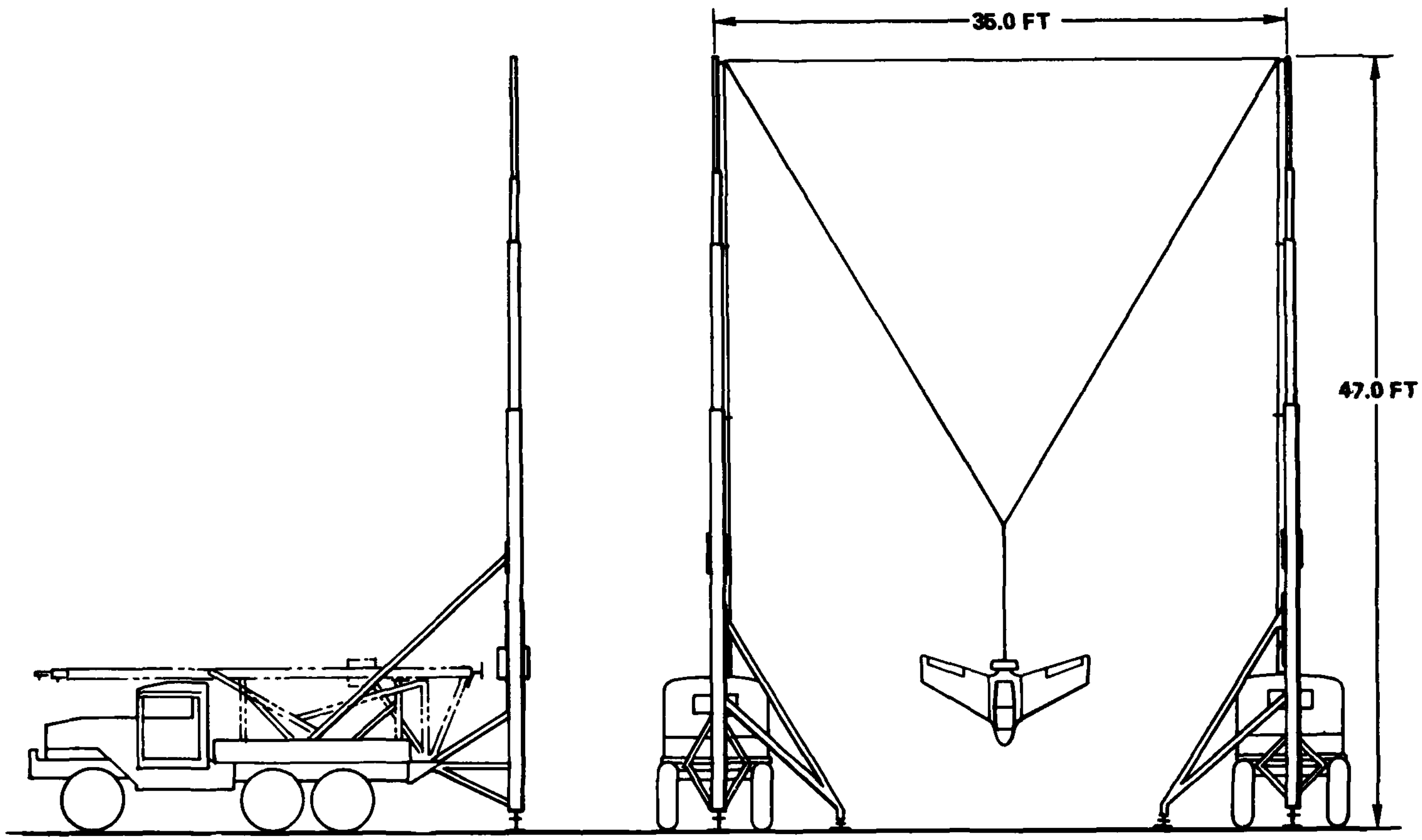


Figure 88. Truck-Mounted (Two M-135s), High-Wire Trapeze

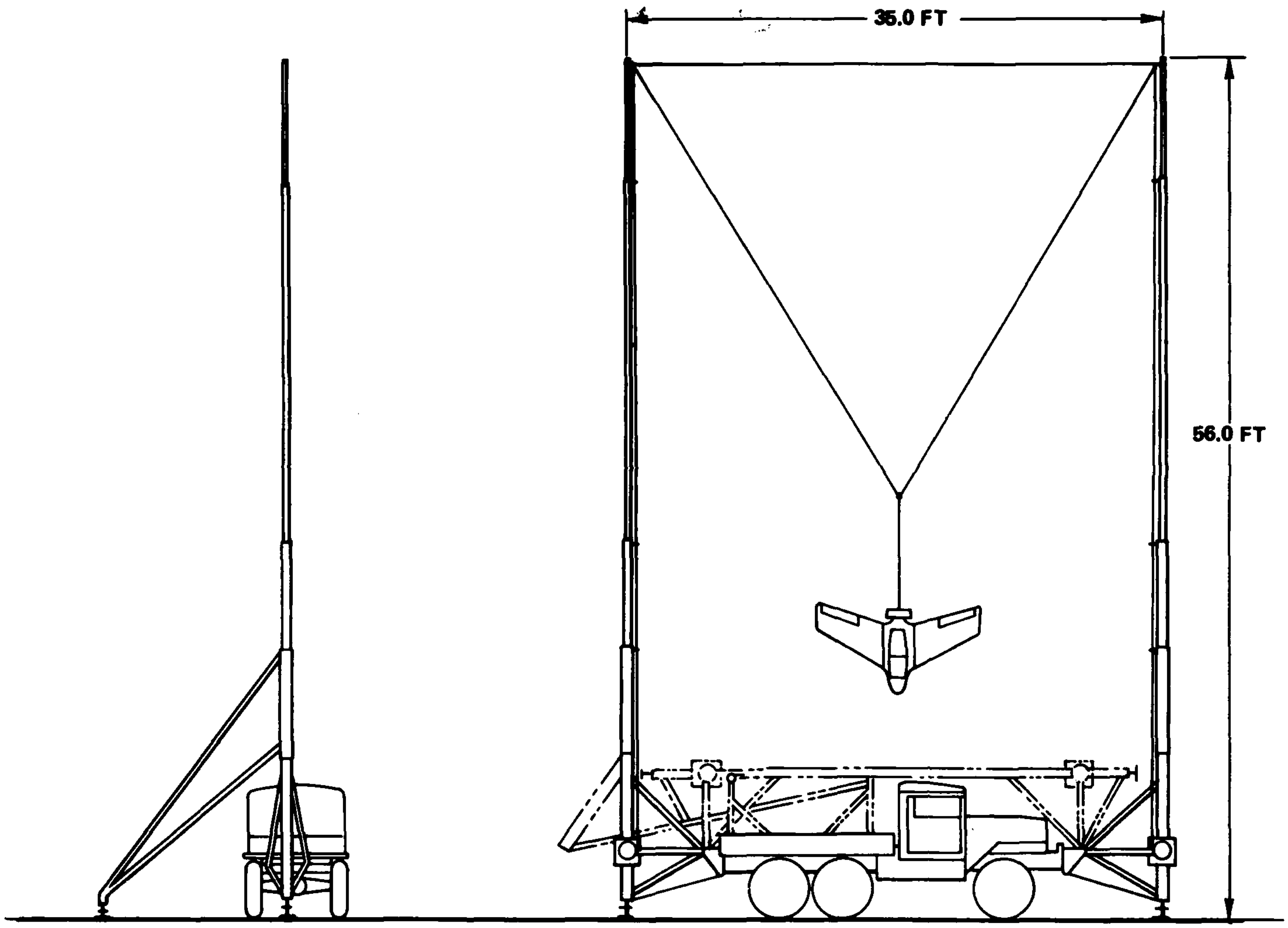


Figure 89. Truck-Mounted (Single M-135) High-Wire Trapeze

intent to the capture net plus I.P. of Figure 33, and its mobile counterpart of Figure 82.

Because of the similarity of the net concepts of subsection 9.3.3 and the wire concepts of this subsection, 9.6.3, the comments under 9.3.3 a, General, may be assumed to apply here.

b. Conclusions

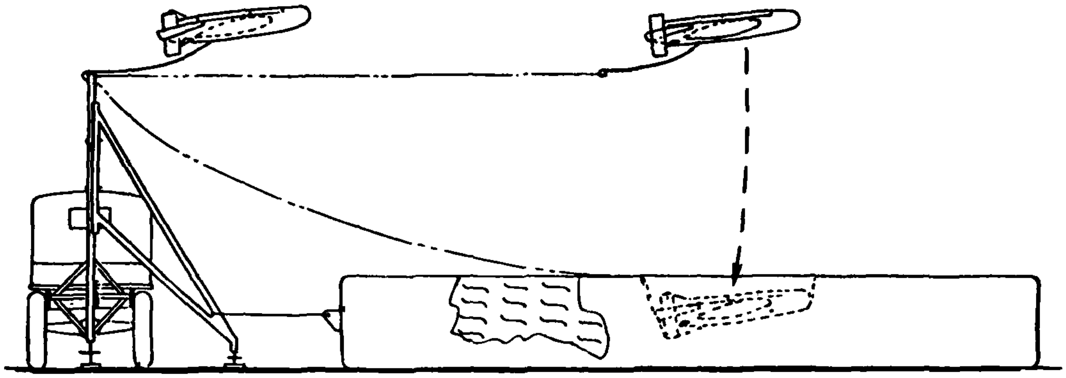
The two truck-mounted wire-plus-impact-platform recovery concepts discussed above appear to involve only moderate engineering and manufacturing problems, and appear to meet the general requirements of tactical deployment.

Either type system could be erected within the desired time and personnel allotment limits.

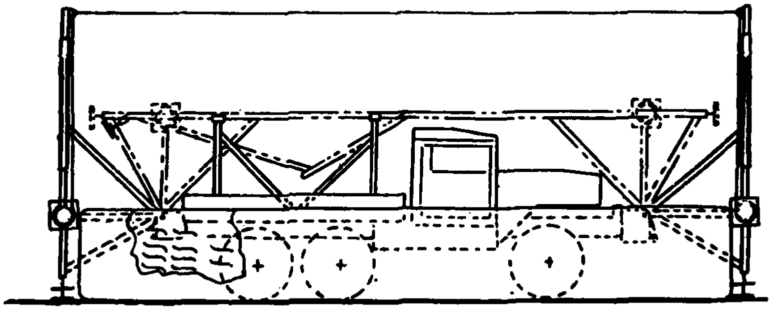
Further study would be required to determine whether the system with the ribbon-type platform could be repositioned and rerigged within 5 minutes to accommodate changes in wind direction.

It appears that the air mat-type could be repositioned in approximately 5 minutes, with reservations if the mat has to be deflated.

A major problem with the concept appears to be achieving high enough reliability of the tail hook engaging the wire when the hook is impacted at any point along its length.



SIDE VIEW



END VIEW

Figure 90. Wire Plus I.P. Mobile Rig

10.0 FINAL EVALUATION AND CONCEPT SELECTION

Of the multiplicity of Mini-RPV recovery systems analyzed, ten were chosen for further evaluation. The other systems were set aside for the reasons given in the analysis of them. The recovery systems chosen for evaluation are:

I-2A	Parachute
I-3A	Retro-rocket
II-1B	Capture Net - Traveling
II-1C	Capture Net - Traveling plus Impact Platform
II-1D	Capture Net - Inflatable Frame
II-3A	Rotary
II-4B	Parachute - Winch-Down
II-4D	Parachute - In-Flight Hookup
II-7A	Arresting Wires - High Wire Trapeze
II-7B	Arresting Wires - Wire plus Impact Platform

The results of the evaluation of these ten Mini-RPV recovery systems are depicted in Figure 91. These results indicate that the parachute recovery system I-2A, is the most viable. The second place system is the traveling capture net, with and without an impact platform, II-1B, and II-1C. In third place is the arresting wire, also with and without an impact platform, II-7A and II-7B. The purpose of the evaluation is to choose one to three, out of the ten, candidates for further analysis. I-2A, the parachute recovery system, is of course, one of the chosen. The data is not sufficient to eliminate the impact platform as a viable option. (It is second best with the traveling capture net concept, and first with the arresting wire concept.) Therefore, the traveling capture net without an impact platform, II-1B is recommended as the other candidate for further study.

The procedure for performing the evaluation begins with the development of a detailed list of parameters describing the Mini-RPV recovery system. Such a list is shown in Table 11. This list should be detailed enough to account for all of the relevant design considerations. The list will contain many items that are incommensurable, either individually or in combination, with other items. Hence, classical methods of cost/effectiveness evaluation are not applicable. These parameters can be made commensurate in the following manner.

On a table such as that shown in Table 12, values for each of the parameters for which they are available are entered. If values are not available, or if the parameter does not lend itself to a quantitative number (e.g., crew skill or safety), the item is scored on a scale of 10 being best. Note that some items, such as the additional weight required to be carried by the RPV, have a value directly related to that parameter (i.e., pounds). Other items are valued according to some other parameter or group of parameters (e.g., the value of "component transportability" is assumed to be equal to the number of M-135 trucks required). Those items not already scored on a scale of 10 being best are then so scored on the basis of the values of the parameters. This scoring involves the ingenuity of the evaluator. For example, the score of item 1.1.1.1, "Additional weight required on RPV" was computed:

Score = 10-1/2 (Weight - 2)

The scores of 2.3.1 and 2.3.2, "Time to set up and dismantle the recovery system", was computed:

Score = 10-1/5 Time

Some items were scored by combining the scores of other items. "Concealment", 2.2.3, was scored by combining the scores of 2.1.1, "set up size of the component" and 2.2.3, "Component Transportability":

Score = Root Mean Square (2.1.1 + 2.2.3)

The same parameter, or item, may occur several times in the list (e.g., reliability, number of personnel, concealment, etc.). Also, some items are scored or valued through a combination of other items. The effect is to weigh certain parameters more highly than others. But, this weighting occurs in a natural manner. The ability to conceal the system, for example, is a function of the set-up size of the recovery system and the number of vehicles that must accompany the system. It is seen then that the depth of the list of parameters itself results in an unbiased weighting.

However, by the accident of the development of the list of parameters, it is noted that the category "Serviceability of Recovery Operations" has a possible score of 160 points, while the category "Cost and Risk" has a possible score of only 80 points. The result is an uncontrollable bias weighting serviceability as twice as important as cost. To delete this bias, each of the major first-level categories is assumed to have equal weight (100 points possible). The second-level scores are then adjusted accordingly. The results are shown in Table 12.

Each of the first-level categories is now weighted according to its presumed importance in determining the design of the system. The assumed weights used are:

1.0	Accommodation by Mini-RPV	25%
2.0	Adaptability to Field Employment	20%
3.0	Serviceability of Recovery Operations	15%
4.0	Suitability for Subdivisional Army Integration	15%
5.0	Cost and Risk	25%

These weights are, of course, judgement factors. Care must be taken that they are not developed to bias one candidate over another. They should be based on an assessment of the weights that the Army will give to each of these factors in its evaluation. The results of this weighting are shown in Figure 91 and in Table 13.

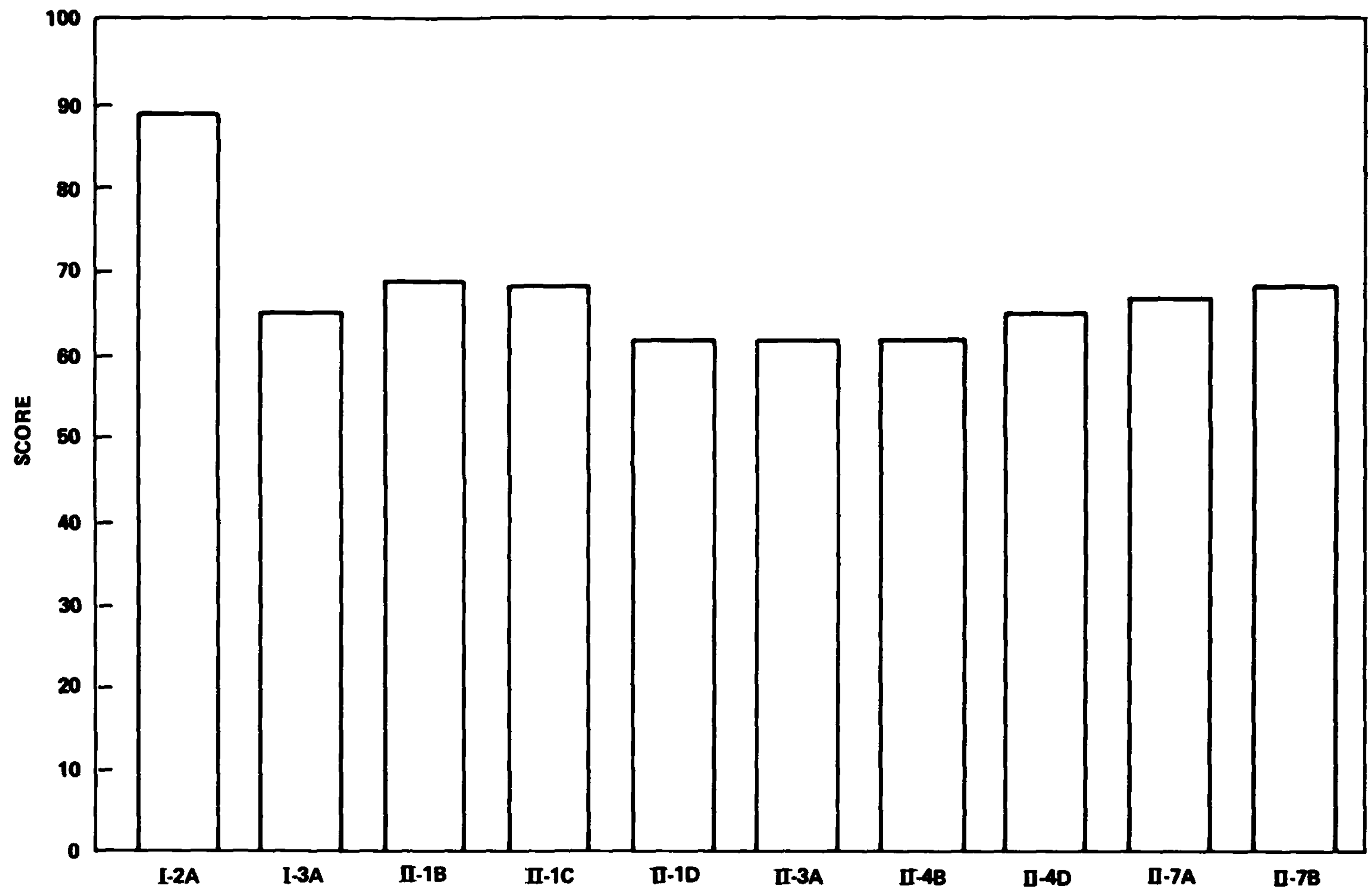


Figure 91. Recovery Concept Evaluation Results

Table 11. RECOVERY CONCEPT PARAMETERS

1.0 ACCOMMODATION BY THE MINI-RPV

1.1 Physical Parameters

1.1.1 Weight
1.1.2 Volume
1.1.4 Impact on RPV design

1.2 Operational Parameters

1.2.1 Guidance and control accuracy
1.2.2 Vehicle dynamic response
1.2.3 Probability of successful recovery
1.2.4 All weather potential
1.2.5 Reliability and maintainability

1.2.5.1 MTBF
1.2.5.2 MTTR

1.3 Tactical Parameters

1.3.1 RPV approach to recovery site
1.3.2 Airborne recovery signature
1.3.3 Mission interface

2.0 ADAPTABILITY TO FIELD EMPLOYMENT

2.1 Physical Parameters

2.1.1 Set-up size of components

2.1.1.1 Height
2.1.1.2 Width

2.1.2 Recovery site area
2.1.3 Edge obstruction height

2.2 Operational Parameters

2.2.1 Crew size
2.2.2 Crew skills
2.2.3 Component transportability
2.2.4 Site prepreparation time
2.2.5 Geological constraints

Table 11, Continued

2.3 Tactical Parameters

2.3.1 Time to set up
2.3.2 Time to dismantle
2.3.3 Detectability
2.3.4 Concealment
2.3.5 World-wide operations

3.0 SERVICEABILITY OF RECOVERY OPERATIONS

3.1 Physical Parameters

3.1.1 Approach window size

3.1.1.1 Height
3.1.1.2 Width

3.1.2 Approachable limit
3.1.3 Reorientation for wind shift time

3.2 Operational Parameters

3.2.1 Automatic/manual recovery operations
3.2.2 Probability of recovery without damage
3.2.3 Time to recover and reset
3.2.4 Guidance and control accuracy
3.2.5 Reliability and maintainability

3.2.5.1 MTBF
3.2.5.3 MTTR
3.2.5.3 Availability

3.3 Tactical Parameters

3.3.1 All weather potential
3.3.2 Access for retrieval
3.3.3 Mission interface
3.3.4 Unusual signatures

4.0 SUITABILITY FOR SUBDIVISIONAL ARMY INTEGRATION

4.1 Physical Parameters

4.1.1 Reduced dimensions for transportation
4.1.2 Packaged weight
4.1.3 M-135 cargo truck compatibility

Table 11, Continued

- 4.1.3.2 Truck modifications required
- 4.1.3.3 number of trucks

4.2 Operational Parameters

- 4.2.1 Number in recovery crew
- 4.2.2 Self-mobility
- 4.2.3 Run for cover capability
- 4.2.4 Logistic compatibility
- 4.2.5 Complexity of operations

4.3 Tactical Parameters

- 4.3.1 Safety
- 4.3.2 Concealment
- 4.3.3 Time to run for cover
- 4.3.4 Mission interface

5.0 COST AND RISK

5.1 Development Costs

5.2 Procurement Costs

5.3 Ownership Costs

- 5.3.1 Training
- 5.3.2 Spares
- 5.3.3 Expendables

5.4 Risk of Alternatives

- 5.4.1 Probability of successful demonstration
- 5.4.2 Probability of meeting costs
- 5.4.3 Survivability 2-5 km from FEBA

TABLE 12. RECOVERY CONCEPTS EVALUATION, RAW SCORES

ITEM NUMBER	EVALUATION PARAMETER	CLASS I				CLASS I					
						CAPTURE NET					
		PARACHUTE		RETRO-ROCKETS		TRAVELING		TRAVELING+IP		INFLATABLE STRUCTURE	
		VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE	VALUE	SCORE
	TOTAL SYSTEM		495.7		387.6		380.5		378		333
1.0	Accommodation by Mini RPV		86		56.6		80.6		80.1		68.1
1.1	Physical Parameters		27		24		40		40		38
1.1.1	Airborne Recovery Components										
1.1.1.1	Weight (Lbs)	16	3	16	3	2	10	2	10	4	8
1.1.1.2	Volume (Ft^2)	.2	8	.15	9	0	10	0	10	0	10
2.0	Adaptability to Field Employment		127.7		126.3		94.2		94.2		87.9
2.1	Physical Parameters		40		40		29.8		29.8		30.0
2.1.1	Set-Up Size of Components										
2.1.1.1	Height (Ft.)	0	10	0	10	26	4.8	26	4.8	15	7
2.1.1.2	Width (Ft.)	0	10	0	10	25	5.0	25	25	25	5
2.2	Operational Parameters		44		41.5		37.0		37.0		27.0
2.2.1	Crew Size (Number)	2	9	2	9	3	8	3	8	4	7
2.2.2	Crew Skills		10		7.5		8		8		7
2.2.3	Component Transportability (Number M-135 Trucks)	.5	10	.5	10	2.5	6	2.5	7	1.5	8
2.3.4	Concealment (2.1.1 + 2.2.3)		10		10		5.3		5.3		6.8

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ITEM NUMBER	EVALUATION PARAMETER	CASE I				
		PARACHUTE			RETRO-R	
		Raw	Adj.	Wt.	Raw	Ad
1.0	Accommodation by Mini-RPV (13)	86	76.5	19.2	56.6	51.
1.1	Physical Parameters (4)	27	22.5		24	20
1.2	Operational Parameters (6)	44	29.3		23.2	15.
1.3	Tactical Parameters (3)	15	25		9.4	15.
2.0	Adaptability to Field Employment (14)	127.7	91.7	18.3	126.3	90.
2.1	Physical Parameters (4)	40	33.3		40	33.
2.2	Operational Parameters (5)	44	29.3		41.5	27.
2.3	Tactical Parameters (5)	43.7	29.1		44.8	29.
3.0	Serviceableness of Recovery Operations (16)	107	83.3	12.5	71.8	57
3.1	Physical Parameters (5)	40	32.3		15.6	13
3.2	Operational Parameters (7)	44	24.4		33.2	18.
3.3	Tactical Parameters (4)	23	25.6		23	25.
4.0	Suitability of Sub-Divisional Army Integration (13)	117	97.7	14.7	101.5	84.
4.1	Physical Parameters (4)	38	31.7		35	29.
4.2	Operational Parameters (5)	49	32.7		41.5	27.
4.3	Tactical Parameters (4)	30	33.3		25	27.
5.0	Cost and Risk (8)	58	96.7	24.2	31.4	51.
5.1	Development Costs (1)	10	25		4	10
5.2	Procurement Costs (1)	10	2.5		6	15
5.3	Ownership Costs (3)	9	22.5		5	12.
5.4	Risk of Alternatives (3)	29	24.2		16.4	13.
	TOTAL Raw (640)	495.7			387.6	
	Adjusted (500)		445.9			335
	Weighted (100)			88.9		

2

TABLE 13. RECOVERY CONCEPTS EVALUATION SUMMARY DATA

CASE I													
	RETRO-ROCKET			CAPTURE NET									
				TRAVELING NET			TRAVELING + IP			INFLATABLE STRUCTURE			
Wt.	Raw	Adj.	Wt.	Raw	Adj.	Wt.	Raw	Adj.	Wt.	Raw	Adj.	Wt.	Raw
19.2	56.6	51.2	12.8	80.6	70.1	17.5	80.1	70.1	17.5	68.1	61.2	15.3	60.
	24	20		40	33.3		40	33.3		38	31.7		34.
	23.2	15.5		30.6	20.1		30.1	20.1		20.6	13.7		16.
	9.4	15.7		10	16.7		10	16.7		9.5	15.8		9.
18.3	126.3	90.9	18.2	94.2	67.8	13.6	94.2	67.8	13.6	87.9	63.6	12.7	102.
	40	33.3		29.8	24.8		29.8	24.8		30	25		30
	41.5	27.7		37	24.7		37	24.7		27	18		38
	44.8	29.9		27.4	18.3		27.4	18.3		30.9	20.6		34.
12.5	71.8	57	8.6	79.1	56.6	8.5	79.1	56.6	8.5	62.6	48.5	7.3	64.
	15.6	13		10.5	8.8		10.5	8.8		9.5	7.9		13.
	33.2	18.4		41.1	22.8		41.1	22.8		33.1	18.4		29.
	23	25.6		22.5	25		22.5	25		20	22.2		22
14.7	101.5	84.7	12.7	84.3	68.4	10.3	83.3	67.6	10.1	75.3	63.1	9.5	78.
	35	29.2		25	20.8		24	20		25	20.8		28
	41.5	27.7		41	27.3		41	27.3		30.5	20.3		34.
	25	27.5		15.3	20.3		18.3	20.3		19.8	22		16.
24.2	31.4	51.]	12.8	47.3	76.1	19.0	46.3	73.6	18.4	39.1	65.9	16.5	36.
	4	10		6	15		7	17.5		7	17.5		5
	6	15		7	17.5		5	12.5		8	20		5
	5	12.5		9	12.5		9	22.5		9	22.5		5
	16.4	13.7		25.3	21.1		25.3	21.1		19.1	15.9		17.
	387.6			380.5			37.8			33.3			342.
		335			339			335.7			302.3		
88.9			65.1			68.9			68.1			61.3	

/

DATA 3

CASE II													
			ROTARY			PARACHUTE						A	
INFLATABLE STRUCTURE						WINCH DOWN			IN-FLIGHT HOOKUP			HIGH-WIRE TRA	
	Adj.	Wt.	Raw	Adj.	Wt.	Raw	Adj.	Wt.	Raw	Adj.	Wt.	Raw	Adj.
.1	61.2	15.3	60.4	55.4	13.9	61.1	53.7	13.4	65.7	54.9	13.7	71.3	63.1
	31.7		34.5	28.7		31	25.8		26	21.7		36.5	30.4
.6	13.7		16.4	10.9		22.3	14.9		32.9	21.9		25.3	16.9
.5	15.8		9.5	15.8		7.8	13		6.8	11.3		9.5	15.8
.9	63.6	12.7	102.7	73.4	14.7	99.4	71.2	14.2	105.4	75.3	15.1	101.9	72.4
	25		30	25		30	25		30	25		27	22.5
	18		38	25.3		35	23.3		40	26.7		38	25.3
.9	20.6		34.7	23.1		34.4	22.9		35.4	23.6		36.9	24.6
.6	48.5	7.3	64.9	5.2	7.8	61.5	47.8	7.2	70.6	53.9	8.1	73.8	56.8
.5	7.9		13.5	11.3		11.4	9.3		11.2	9.3		10.5	8.8
.1	18.4		29.4	16.3		31.3	17.4		38.4	21.3		40.3	22.4
	22.2		22	29.4		19	21.1		21	23.3		23	25.6
.3	63.1	9.5	78.4	64.1	9.6	82.7	69	10.4	91.2	75.5	11.3	91.8	75.1
	20.8		28	23.3		26	21.7		28.5	23.8		30.5	25.4
.5	20.3		34.2	22.5		25.5	23.7		40.5	27		41.5	27.7
.8	22		16.2	18		21.2	23.6		22.2	24.7		19.8	22
.1	65.9	16.5	36.1	61.8	15.5	40.1	63.4	15.9	42.1	66.8	16.7	43.7	68.1
	17.5		5	12.5		5	12.5		6	15		5	12.5
	20		5	12.5		5	12.5		6	15		5	12.5
	22.5		5	12.5		8	20		7	17.5		9	22.5
.1	15.9		17.1	14.3		22.1	18.4		23.1	19.3		24.7	20.6
.3			342.5			344.8			37.5			382.5	
	302.3			306.7			305.1			326.4			335.5
		61.3			61.5			61.1			64.9		

4

	ARRESTING WIRE					
OOKUP	HIGH-WIRE TRAPEZE			WIRE + IP		
Wt.	Raw	Adj.	Wt.	Raw	Adj.	Wt.
13.7	71.3	63.1	15.8	70.8	62.7	15.7
	36.5	30.4		36.5	30.4	
	25.3	16.9		24.8	16.5	
	9.5	15.8		9.5	15.8	
15.1	101.9	72.4	14.5	99.6	71.4	14.3
	27	22.5		30	25	
	38	25.3		36	24	
	36.9	24.6		33.6	22.4	
8.1	73.8	56.8	8.5	70.8	55.1	8.3
	10.5	8.8		10.5	8.8	
	40.3	22.4		37.3	20.7	
	23	25.6		23	25.6	
11.3	91.8	75.1	11.3	86.7	70.6	10.6
	30.5	25.4		27	22.5	
	41.5	27.7		111.2	27.5	
	19.8	22		18.5	20.6	
16.7	43.7	68.1	17.0	47.8	76.5	19.1
	5	12.5		7	17.5	
	5	12.5		6	15	
	9	22.5		9	22.5	
	24.7	20.6		25.8	21.5	
64.9	382.5	335.5	67.1	375.7	336.3	68

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11.0 PHASE III STUDIES

11.1 Introduction

The Mini-RPV recovery concepts remaining from the evaluations of Phase II, shown in Table 14, are examined further, including cost information, in Phase III for the purpose of determining a preferred recovery system, if possible. The subject concepts are:

Group I - Surface-Impact

- Nongliding Chute, Concept I-2A

Group II - Above-Surface Recovery

- Traveling Net, Concept II-1B
- Traveling Net Plus Impact Platform, Concept II-1C

Later information on the capture net family of concepts (Reference 31) has provided two spin-off versions of the traveling net concept II-1B which are designated:

"High Net Recovery System", Concept II-1B-1
"Modified High Net Recovery System", Concept II-1B-2

and additional work on the traveling net plus impact platform, Concept II-1C, involving an air mat platform is designated:

"Low Net/Air Inflated Platform", Concept II-1C-1

The nongliding chute concept I-2A and the three newer versions of the capture net family, II-1B-1, II-1B-2 and II-1C-1 are the subjects of Phase III studies in the following paragraphs.

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31. Nissley, W. J., TECHNICAL DATA PACKAGE, HIGH NET RECOVERY SYSTEM MODIFIED HIGH NET RECOVERY SYSTEM, & LOW NET/AIR INFLATED PLATFORM, All American Engineering Co., Wilmington, Del., February 17, 1977.

TABLE 14. CONCEPTS SELECTED FOR PHASE II STUDY

		A	B	C	D
GROUP I SURFACE IMPACT	I-1 RUNWAY				
	I-2 PARACHUTE	NONGLIDING			
	I-3 RETRO ROCKET				
	I-4 STOWED ROTOR				
	I-5 SPIN RECOVERY				
GROUP II ABOVE-SURFACE-RECOVERY	II-1 CAPTURE NET		TRAVELING	TRAVELING + I.P.	
	II-2 INCLINED RAMP				
	II-3 ROTARY (CAROUSEL)				
	II-4 PARACHUTE				
	II-5 AERIAL TRACK				
	II-6 'U' CONTROL				
	II-7 ARRESTING WIRES				
	II-8 TETHERED AERIAL				
	II-9 BRUSH ATTENUATOR				

11.2 Nongliding Chute, Concept II-2A

11.2.1 General. The nongliding chute recovery concept was pointed out to be a credible concept in Phase I, subsection 7.2.2, and was carried over to Phase II, subsection 9.1.2 for further study. In Phase II, available data including weights and parametric chute characteristics were summarized for the purpose of Phase II evaluations from which it emerged as a candidate for Phase III studies. A systems approach in the early stages of RPV design would be necessary in order to properly integrate the chute subsystem. However, in Phase III, and within the scope of this study, basic elements of a systems approach are discussed to provide information for evaluating the chute concept.

Requirements

In addition to the overall guidelines and criteria for Mini-RPV recovery studies outlined in Section 3.0, further requirements for a parachute system are listed below:

- High Reliability (Deployment and Operation)
- High Specific Drag Parameter, $C_{D_O} S/W_P$ (a figure of merit emphasizing high aerodynamic drag and low weight) (See Reference 2.)
- Low Packed Volume
- Reasonable Stability (Desired to minimize horizontal velocity component at impact)
- Deployment Altitude 150 to 200 feet.
- Moderate Opening Shock Factor
- Positive chute separation from RPV at Impact
- Minimal Damage of RPV upon Surface Impact
- Maximum Simplicity of Fabrication for Chute(s) and Other System Components
- Low System Cost
- Low Maintenance and Service

Nongliding Parachute Definition

As noted earlier in this study (subsection 7.2) the nongliding chute was arbitrarily defined as one for which no special design provisions are made to purposely induce gliding performance, and an arbitrary L/D = 0.6 cut-off was stipulated to separate the nongliding from gliding types. Actually all of the solid textile type canopies glide and/or oscillate to various degrees. The familiar flat circular canopy, for which no reference has been found that specifies an L/D value, either oscillates or glides at an angle near 30 degrees (Reference 32) thus implying an L/D capability of about 0.5. Some solid textile canopies such as the triconical, seem to combine L/Ds of 0.5 to 0.6 with small oscillation angles of about ±5 degrees. The geometrically porous chute types have low or zero L/D values and generally are much more stable than the solid textile types.

11.2.2 Candidate Chute Types. In common with other technologies that have grown over the years, parachute terminology is sometimes confusing in that no one glossary of chutes seems to include all types. For the purpose at hand, the apparent types to consider are listed below:

Solid Textile

- Flat circular
- Extended skirt
- Guide surface (also ribless)
- Conical
- Triconical
- Shaped gore

---

32. Huntley, I; Cockrell, D. & Ayres, R; "Design for Descent - Parachute Technology", FLIGHT INTERNATIONAL MAGAZINE, 27 March 1975.

* Scalloped skirt
* Parasheet

Geometrically Porous

* Cross
* Disk gap
* FIST (ribbon)
* Ring slot
* Ring sail
* Airfoil (not to be confused with parafoil, etc.)
* Rotary (vortex ring and rota-foil)

From the solid-textile group the flat circular and the triconical are selected as being representative of viable candidates for Mini-RPV recovery purposes. The other six chutes listed appear to either offer little significant improvement over the flat circular, or the ones that do, such as the guide surface types, are much more expensive to manufacture. In the high-geometric-porosity group the cross chute would be by far the simplest and the least expensive chute to manufacture.

Additional data on the three selected candidate chutes are presented in Table 15.

The flat circular canopy, according to Reference 10, is reliable, relatively easy to manufacture, and is generally limited to low-speed uses because it opens rapidly and has excessive opening shock. The definition of "low-speed" here is perhaps irrelevant, in that Reference 10 alludes to deployment velocities of 180 to 275 knots. Whereas velocities of about 80 knots or less is the area of interest for the Mini-RPV. It has a moderate C_{D_O} value, and is unstable in that oscillations of ± 30 degrees are sometimes experienced. The flat circular chute has been widely used as a personnel chute and, as noted earlier, was used in an interim recovery system for the trial Navy STAR Mini-RPV.

The triconical chute has been used principally for personnel applications. It features a relatively high C_{D_O} value, and is stable. However, its L/D value of 0.5 to 0.6 implies an appreciable horizontal velocity component at ground impact.

The cross chute, which derives its name from the fact that it consists of two rectangular fabric panels laid 90 degrees to each other in the form of a cross, until recently was, generally thought of as a drag chute for high speed, even supersonic applications, under which conditions its drag coefficients are relatively low (Reference 33). However, as noted in Reference 34, C_{Do} increases rapidly at the lower equilibrium velocities and a test point value of 0.69 is indicated for a V_v = about 25 feet/second.

A peculiarity of the cross chute is a tendency to rotate, or spin when the permeability of the fabric is low. However, a simple lightweight swivel that would operate satisfactorily for periods of 10 to 12 seconds at a time would appear to alleviate the spin problem should it occur.

11.2.3 Subsystems Definitions

Parachute Subsystem

A brief description of the basic elements of a ground-impact parachute recovery system is presented in block diagram form in Figure 92.

Block I includes the items related to the chute installation proper, and Block II indicates the major items related to the airframe structure. Block III notes the need for a chute riser release to preclude damage to the RPV from being dragged on the ground after impact. The riser release would normally be triggered automatically, but a command override would backup the automatic features. The parachute compartment door latch, Block IV, would be actuated in conjunction with, or slightly after, engine cutoff, Block V. The command logic and the electrical power supply are Blocks VI and VII which complete the diagram.

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33. Ludtke, W. T., EFFECT OF CANOPY GEOMETRY ON DRAG COEFFICIENT OF A CROSS PARACHUTE IN THE FULLY OPENED AND REEFED CONDITIONS FOR A W/L RATIO OF 0.264, Naval Ordnance Laboratory, Silver Spring, Mo., Report NOLTR 71-111, Report NOLTR 71-111, 20 August 1971.

34. Niccum, R. J.; Haak, E. L.; Gutenkauf, R.; DRAG AND STABILITY OF CROSS TYPE PARACHUTES, TECHNICAL DOCUMENTATION REPORT FLD-TDR-64-155, University of Minn., Minneapolis, Minn., February 1965.

TABLE 15. CANDIDATE CHUTES

V_v = 20 ft/sec @ 4,000 Ft 95^{o}F, Chute Dia 20 to 30 ft

Deployment Velocity: 78 knots max.

TYPE	C_{D_o}	L/D	STABILITY	OPENING SHOCK FORCE, g s	DEPLOYMENT ALTITUDE
Flat Circular	.75	-	Unstable $\pm$ 30^o	4 to 5	150 to 200 Feet
Tri Conical	.87	.5 to .6	Stable $\pm$ 5^o		
Cross	.69	Nil	Stable $\pm$ 2^o		

Impact Attenuation Subsystem

In the event that an impact attenuation system, such as air bag(s), is installed, the block diagram of Figure 93 depicts typical basic elements based on stored gas actuation.

It will be noted that in the parachute system, Figure 92, that structural provisions would be included for impact attenuation, which would cover strictly basic structure or backup items such as a streamlined belly-bubble that would take impact loads and spring back into position.

11.2.4 Analysis

Chute Characteristics

Characteristics of the three selected chute candidates are presented for the 120- and 200-pound class RPVs in Table 16.

The numbers shown, based on available, and sometimes very limited information, are approximations but they represent "as obtained" data.

However, some speculation is in order to attempt to normalize some of the numbers in Table 16 and to establish more optimistic objectives for the Mini-RPV recovery chute in general.

Probably the most conspicuous anomaly in Table 16 is the relatively low weight estimated for the cross chute despite its much larger area. The principal reasons for this apparent discrepancy are: (1) these data are based on the NAVY/APL PRD-2 Mini-RPV cross chute, which employed 3/4 ounce rip-stop nylon canopy material; and (2) the cross chute had only 12 suspension lines. These factors resulted in a basic unit weight of 0.0094 lb/ft^2 (Reference subsection 7.2 and Table 16) and a total unit weight, adding 20 percent for ancillaries, of 0.0113 lb/ft^2.

The lowest fabric weight noted for the other type chutes is 1.1 oz/yd^2. Based on the 756-square foot area shown for the cross chute for the 200-pound RPV in Table 16, the difference between 3/4 ounce and 1.1 ounce nylon, neglecting seam folds, etc., amounts to approximately 1.8 pounds.

Much more experimental work would be required to substantiate the use of the lighter fabric weight, especially for the 200-pound class RPV. Some slight degree of confidence in the light fabric may be gained from a reported unintentional deployment of the 80-pound PRD-2's cross chute at 120 knots.

Thus, if we were to correct the triconical and circular chute weights down to 3/4 ounce nylon based on a delta weight of 0.35 oz/yd^2, the chute weights would compare as follows:

Chute Installed Weights, 3/4-oz Canopy Fabric

	120-lb RPV	200-lb RPV
Triconical	5.13 lb	8.54 lb
Flat Circular	5.65 lb	9.41 lb
Cross Chute	5.12 lb	8.53 lb

By making use of Kevlar material for suspension lines the total installed chute weight could be reduced by approximately 8 percent. The chute installed weights then become:

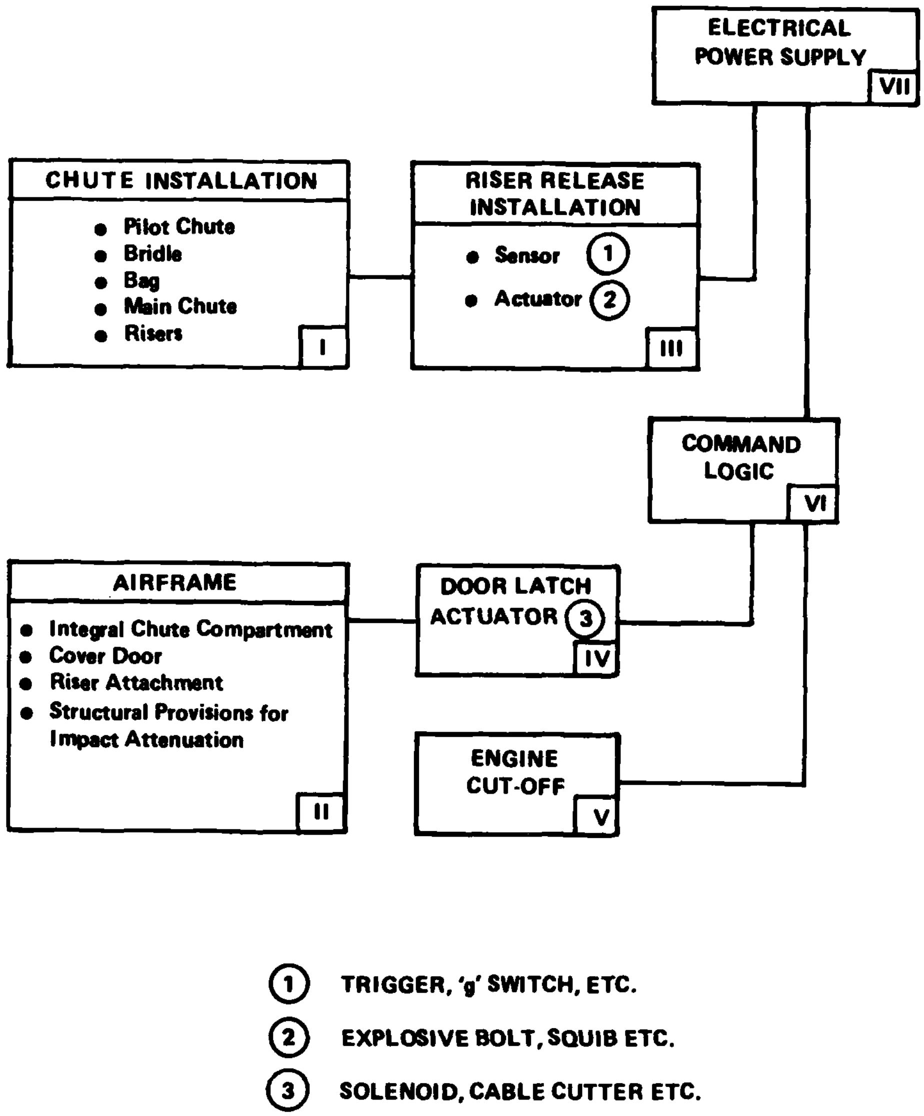


Figure 92. Block Diagram, Chute Subsystem

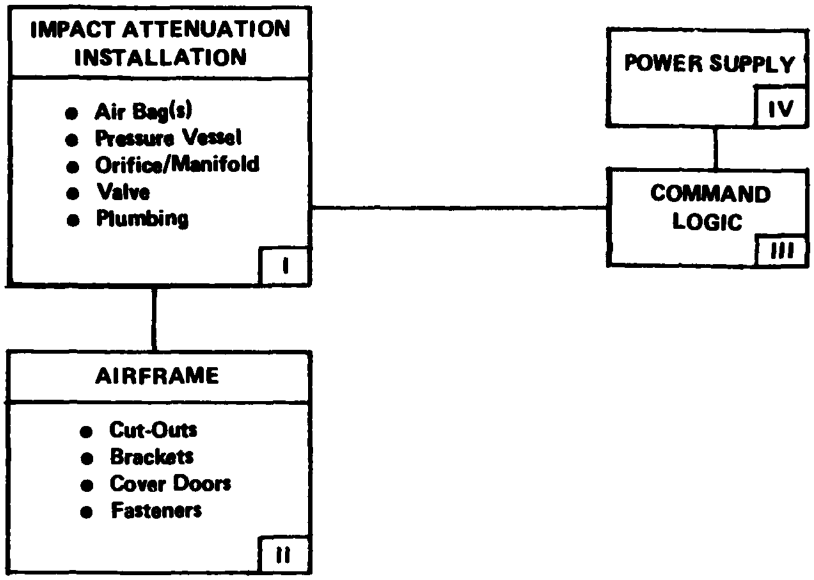


Figure 93. Block Diagram Air Bag Impact Attenuator Subsystem

Chute Installed Weights, 3/4-oz Fabric & Kevlar Lines

	120-lb RPV	200-lb RPV
Triconical	4.72 lb	7.86 lb
Flat Circular	5.20 lb	8.67 lb
Cross Chute	4.71 lb	7.85 lb

Thus the installed chute (chute, suspension lines, riser, bag, pilot chute, and bridle) weights would be between 3.9 and 4.4 percent RPVs gross weight. With the goal of 7 percent gross weight for the total of the airborne recovery system, the following allowances for the remainder of the system, including any provisions for impact attenuation, would be:

Recovery Provisions Allowance

	120-lb RPV	200-lb RPV
Triconical	3.68 lb	6.14 lb
Flat Circular	3.20 lb	5.33 lb
Cross Chute	3.69 lb	6.15 lb

Thus it is conceivable, by optimizing Mini-RPV parachutes and impact attenuation provisions, that an allowance of 7 percent of the gross RPV would be sufficient.

A physical size comparison of the three chutes discussed above is depicted in Figure 94. Plan views in terms of the constructed diameter, D_C, and the L and W dimensions for the cross chute are shown. It will be noted that D_C for the triconical chute is approximately $D_O/1.08$.

Equations

Equations used to derive data for Table 16 are:

Surface area, S , triconical and flat circular

$$V_V = \sqrt{W/D_{Do} \frac{\rho}{2} S_O} \tag{38}$$

which, for 4000 feet, 95°F atmospheric conditions can be reduced to:

$$V_V = 32.3\sqrt{W/C_{Do} S_O} \tag{39}$$

Solving for S_O

$$S_O = 1043.297\ W/C_{Do} V_V^2 \tag{40}$$

for the 120-pound RPV at V_V = 20 feet/second Equation (40) becomes:

$$S_O = 312.989/C_{Do} \tag{41}$$

and for the 200-pound RPV at V_V = 20 feet/second Equation (40) becomes

$$S_o = 521.648/C_{Do} \tag{42}$$

Surface area of the cross chute

$$S_o = 2LW - W^2 \tag{43}$$

where

L = panel length
W = panel width
for a W/L ratio of 0.333:

$$L = \sqrt{S_o/0.5551} \tag{44}$$

Weights

$$\text{Weight} = (\text{basic unit wt.} \times 1.20)S_o \tag{45}$$

where the unit weights are taken from subsection 9.2, and 1.20 is the factor used to account for the chute ancillaries. The total unit weights are:

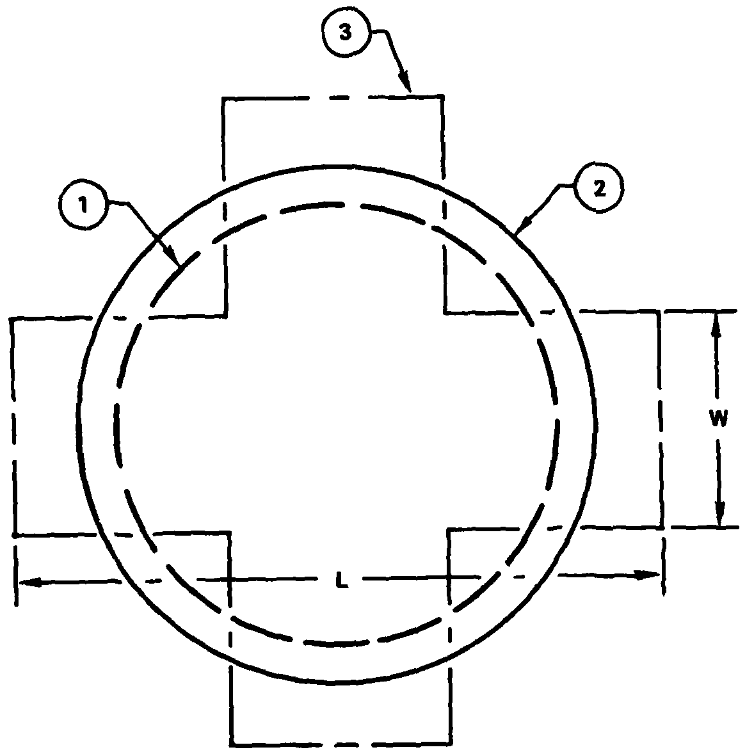
Triconical	.0139 (1.2)	=	.0167 lb/ft^2
Flat Circular	.0133 (1.2)	=	.0160
Cross Chute	.0094 (1.2)	=	.0113

11.2.5 Parachute Cost Information The following cost information was obtained as a follow-on to Reference 14, and represents budgetary quotations for planning purposes only. All cost numbers are rounded off to the nearest whole number.

Cost data for the nongliding ($L/D \leq 0.6$) triconical type chute are tabulated below. A nonrecurring charge of $5465 would be applicable for each configuration.

TABLE 16. CHARACTERISTICS, CANDIDATE PARACHUTES

CHUTE TYPE	DRAG COEFFICIENT C_{D_0}	SURFACE AREA S_0, FT^2	NOMINAL DIAMETER D_0, FT	CHUTE INSTALLATION WEIGHT, LB	CANOPY LOADING, $= \frac{\text{RPV + CHUTE WT}}{S_0}$	VOLUME (30 LB/FT^3) FT^3, (IN^3)
			120-LB RPV			
TRI CONICAL	.87	359.8	21.4	6.0	.350	.200 (346)
FLAT CIRCULAR	.75	417.3	23.1	6.7	.304	.223 (385)
CROSS (W/L= .333)	.69	453.6	L = 24 W = 8	5.1	.276	.170 (294)
			200-LB RPV			
TRI CONICAL	.87	599.6	27.6	10.0	.350	.333 (576)
FLAT CIRCULAR	.75	695.5	29.8	11.1	.304	.370 (639)
CROSS (W/L= .333)	.69	756.0	L = 36.9 W = 12.3	8.5	.276	.283 (490)



	D_C, FT	S_O RATIO
1 TRICONCIAL	25.6	1.0
2 FLAT CIRCULAR	29.8	1.15
3 CROSS L =	36.9	1.26
W =	12.3	

Figure 94. Chute Planview Dimensions

	Price/Each ($)			
	120-lb RPV		200-lb RPV	
Lines	Nylon	Kevlar	Nylon	Kevlar
Quantity				
1 each	471	1084	563	1173
10 each	384	463	469	578
50 each	359	437	441	549

Quotations on quantities of one each for Kevlar lines are based on a minimum yardage which must be purchased.

The above tabulated figures represent a 0.955 learning curve from which costs at quantities of 1000 units are estimated at $294 each for the 120-pound RPV and $361 for the 200-pound RPV, both with nylon lines.

A procurement (development) schedule that would nominally apply to the triconical type parachute is:

Quantity	Days ARO
1 to 10 ea	90
50 ea	
First 25	105
Next 25	30 (135)

11.2.6 Impact Attenuation The subject of ground impact related to recovery implies that provisions of some form be made to attenuate impact energy to protect the RPV from damage. Horizontal impact velocities must be considered as well as the vertical velocities. Under wind conditions, a perfectly stable parachute would still subject the RPV to horizontal impact forces. Most parachutes have some gliding and/or oscillating tendencies which aggravate the situation. The most prominent forms of impact attenuation in use, or under consideration for RPVs are:

Structural

Rigid Structure
Crushable components
Rebound structure

Deployable Attenuators

Retro rockets

Air bags
Deployable crushables

Structural

Rigid Structure

A notable example of the beefed-up structure, or brute force school of impact attenuation, is Teledyne Ryan Aeronautical's BQM-34A target drone. The impact attenuation provisions consist chiefly of a built-up horseshoe frame at the low-point in the nacelle most likely to contact the surface of the earth first.

The design impact load for the BQM-34A is $n_z W$ = 20,000-pound where n_z is the vertical load factor, and W is the recovery weight. At the normal recovery weight of 1400 pounds, the design load factor n_z is:

$$n_z = 20{,}000/1400 = 14.3 \text{ g}$$

However, BQM-34A vehicles have withstood vertical load factors of over twice the design factors at impact.

The results of four ground surface impact recoveries for the AQM-34 recorded in Reference 35 are summarized in Table 17. The two tests at 1700-pound recovery weight are without wing fuel pods, and the two tests at 2285-pounds are with pods. This brief sampling of surface impact recoveries shows that appendages are sometimes damaged with this type air vehicle configuration when no damage occurs to the belly of the nacelle, the principal impact structure. The maximum rigid body vertical load factor at the C.G. averaged 9.6 g with a 12.0 peak at vertical rates of descent from 15 to 18 feet/second.

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35. Triplett, J. A., AQM-34 G-SWITCH INVESTIGATION AIR FORCE FLIGHT TEST CENTER, EAFB, CA., AFSC Report No. AFFTC-TR-75-46, Dec. 1975.

As noted in subsection 7.2.1, the Navy/TRA Model 262 (STAR) Mini-RPV, without special provisions for surface impact, was recovered with only moderate damage. The major load was taken by a simulated plastic optical dome attached rigidly to the belly of the RPV. On one occasion only cleaning the RPV was required before it was ready for launching.

It appears that RPV's with only rigid structure could be designed for impact load factors of 12 to 14 g. It follows that proper thought in the early stages of design would be necessary in order to prevent damage with such load factors.

Table 17. AQM-34 SURFACE IMPACT TESTS

Recovery Wt, lb	V_v, ft/sec	V_{wind}, knots	Vert Accel at C.G., g	Remarks
1700	15	5	11.0	No impact damage to nacelle horizontal stabilizer end plate damaged.
1700	12	3	7.2	No impact damage. Moderate damage due to being dragged. Chute release was accidentally disarmed.
2285	14	6.2	8.0	Appreciable impact damage to nacelle due to pod pylon attachment failure.
2285	18	6.2	12.0	No impact damage to belly of vehicle; pods and one wing tip slightly damaged.

Crushable Components

An example of crushable components added for impact protection is the MBLE Epervier X-5 (subsection 7.2.1), an RPV with a recovery weight of about 290 pounds. Foam-filled fiberglass ventral fins are incorporated in this vehicle as the principal means of impact attenuation. The damage occurrence statistics for the X-5 are not known. However, the performance of the system is apparently acceptable for operational use.

Another example of energy attenuation by means of crushable components is the Army/Beech MQM-107 VSTT RPV, which recovers by chute in the nose-down attitude, landing on a replaceable nose cone filled with crushable material. The recovery weight of the VSTT is estimated at 700 pounds, and the descent rate at about 22 feet/second, under which conditions the maximum impact load factor is about 13 g.

Honeycomb material in various forms can be used as crushable energy absorbers. Radially expanded honeycomb was investigated in the early 1960s but apparently was not developed further (Reference 36). Newer forms of honeycomb, such as trussgrid, offer crushable materials at 50 to 80 percent deformation efficiency with an unusually uniform retarding force while being loaded.

Rebound Structure

The rebound type structure is conceptual at this point. It would consist of a streamlined belly-bubble or material such as Kevlar-Epoxy which has high impact strength. The bubble would contain only air at atmospheric pressure. Some energy would be absorbed by displacing the air through small orificies. Hopefully, this modification of the brute force approach would be sufficient for acceptable performance with a Mini-RPV.

Deployable Attenuators

Retro Rocket

In the deployable attenuator field, the retro rocket concept would decelerate the mass of the RPV to a much lower value than that of the chute's normal stabilized rate of descent. The retro rocket scheme was employed by the Red Headed Road Runner Missile and perhaps other applications. As pointed out in Reference 36, the retro rocket problem areas include inability to handle off-design vertical energy, to attenuate horizontal energy and in the control of the time of firing the rocket. The location of the retro rocket presents design problems in that if it is located in the chute suspension system, say the risers, the RPV is subject to damage as the rocket case drops after firing. Locating the rocket(s) in the RPV airframe makes the alignment with the C.G. more critical than if suspended above the RPV. Also, the hazards of blast damage and setting fire to dry grass in the recovery area (Reference subsection 7.3) are present.

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36. Mehaffie, S. R., STATE OF THE ART OF IMPACT ATTENUATION CONCEPTS FOR RPV APPLICATIONS, AFFDL, Wright-Patterson AFB, Ohio, Technical Memorandum, AFFDL-TM-76-51-FER, May 1976.

Air Bag

The air bag energy attenuator concept has been developed for several air vehicle applications. A twin air bag system was flight-tested on the USAF Martin TM-76 MACE drone aircraft (at the time called a self-guided missile) in the late 1950s with apparently reasonable success. The TM-76's recovery weight was about 10,000 pounds. With a rate of descent of 27 feet/second, the vertical kinetic energy was about 114,000 foot-pounds and a maximum load factor of about 10 g was developed.

A triple air bag recovery system was flight-tested successfully on the USAF/TRA AQM-91A at recovery weights of about 3500 pounds. In Reference 36 other applications are listed as the X7A, GAM-72 and XQ-4A, and the F-111 and B-1 emergency escape capsules.

Laboratory tests (Reference 3) on a USAF/TRA MQM-34D (similar in configuration to the BQM-34A), equipped with an air bag attenuator located under the nacelle showed indications of considerable improvement (5 to 7.5 g) over the direct ground impact results of the BQM-34A measured at the RPV's C.G.

In the Mini-RPV field, the Navy/APL PRD-2 RPV noted in subsection 7.2 incorporated a remarkably simple thermoplastic bag system operated by a life-raft CO_2 bottle. The complete recovery system for the PRD-2 is reported to weigh 5.4 pounds, including a cross chute of about 3 pounds. The total of 5.4 pounds amounts to about 6.8 percent of the 80-pound gross weight of the RPV. There is no strong evidence at this point indicating that a combination chute/air bag system could be designed for less than 7 percent of the gross weight of the 120- or 200-pound class RPVs of this study. However, there is likewise no substantial evidence against keeping 7 percent as a goal. An objection noted for air bag attenuation systems is a tendency for the bag to fold under due to horizontal motion of the RPV at impact. This problem can probably be solved with proper design at the outset.

Deployable Crushables

Under the heading of deployable crushables, the foam-in-place concept has been revived recently (Reference 36) under the impetus of reduced "curing times" for the foam and other improvements in the process. The foam-in-place system involves injecting two separately stored chemicals into a mixing nozzle to create the foam which fills a bag to form a crushable mass capable of absorbing impact energy. The two chemicals are stored in tanks pressurized by an inert gas at 200 to 250 psi. Mainfold feedlines lead from the tanks to a valve which could be of the frangible diaphragm type mechanically or pyrotechnically actuated.

Reference 36 states that testing to date has been with a polyurethane foam having a rise-time of 30 seconds and a compressive strength of approximately 14 psi at 120 seconds. It appears that the anticipated parachute recovery time for the Mini-RPV of 10 to 12 seconds from chute inflation to ground impact may be incompatible with the rise-time characteristics noted above unless the foaming operation could be programmed with some lead time. Also, a subsystem for a Mini-RPV would have to be defined in more detail to properly understand the implications of weight, volume, cost, and operating limitations.

11.2.7 Conclusions. The three types of parachutes examined above, the triconical, flat circular, and the cross chute represent a variety of characteristics which could only be completely sorted out by studies in greater depth. At the level of study possible in this report either of the three might be selected, depending on where the emphasis on performance is placed, since the projected weights and packed volumes are not notably different.

Detailed optimization studies are needed to determine the most suitable type of recovery parachute for given Mini-RPV configurations. The studies could be done in two phases. First, detailed trade-off studies would be conducted to select a type(s) of chute (including its ancillary items) for minimum weight, volume, cost, and other criteria. Next, the selected type, or types, of chute installation could then be studied in terms of the peculiarities of specific Mini-RPV designs during their early stages where effective subsystems integration is possible for the chute, airframe and impact attenuation provisions.

One factor that may make a marked distinction in the chute-recovered RPVs configuration and design complexity with respect to the chutes stowed location and impact attenuation provisions is the use of an optical sensor dome that apparently must protrude from the bottom of the RPV. A possible solution to the dome problem is to deploy the chute such that the RPV lands on its back such that impact provisions are minimal. Other possible solutions are: (1) retracting the black-box to which the dome is attached, making use of the forces available in the chute riser lines, (2) an air bag shock attenuation system, (3) extendable flexible skids, hoops, or similar structure to take impact and to protect the dome, or (4) rotating the part of the airframe containing the dome through 180 degrees.

Unfortunately, as mentioned earlier in this study, the energy-absorbing stroke dimension for a given descent velocity and load factor objective does not scale down with the weight of the vehicle involved. Therefore, at the same absorber system efficiency, the stroke required to decelerate a large, heavy object would be the same as for a 120-pound Mini-RPV.

In any event, it appears that the simpler approaches to impact attenuation for Mini-RPVs should be exploited before resorting to the more sophisticated forms. Limited experience with the MBLE Epervier X-5 and the Navy/TRA Model 262 Mini-RPV (Section 7.2) indicate that these system have some degree of feasibility for the simple approaches.

11.3 Capture Net, Concept II-1

11.3.1 Introduction. As noted in the introduction to Phase III discussion, Section 11.0, the three newer versions of the capture net family are the subjects of Phase III studies. The designations of the newer versions are repeated here for reading convenience.

- High-Net Recovery System, Concept II-1B-1
- Modified High-Net Recovery System, Concept II-1B-2
- Low-Net/Air Inflated Platform, Concept II-1C-1

Cost information quoted hereafter for the net recovery systems is budgetary data to be used for planning purposes only. Truck modification costs of GFE vehicles are included.

A development program schedule that would nominally apply to any of the three spin-off net recovery systems mentioned above is:

Task	Months ARO
• Analysis & Design	2
• Manufacture	3
• Test	1
Total Time to Deliver	Δ6

11.3.2 High-Net Recovery System, Concept II-1B-1

a. General

The high-net version of the traveling net concept is illustrated in Figure 95 (a) and (b). Conceptually, it differs from the configuration of Figure 81 principally in that the net system is installed on one M-135 truck, and a net low-line (bottom corners of the net) retraction system has been included.

The one-truck arrangement requires net support stanchions 50 feet in height for the 200-pound class RPV to allow the RPV to swing freely above the truck after capture. The stanchion height is limited to 50 feet through the use of the line retraction system, and by removing the cab top of the truck.

The line retraction system for this concept (Figure 95(c)), actuated by a pneumatic cyliner, shortens the swing-back length of the net with the RPV in it about 10 percent after arrestment by the energy-absorbing system. The retract cylinder works through a line reeving system terminating at the lower corners of the recovery net.

The energy absorber is an 18-inch diameter rotary hydraulic water turbine type. The absorber's retarding force is distributed to all four corners of the recovery net (Figure 95 (c)).

Lines to the lower corners of the recovery net are lowered by releasing pressure in the pneumatic cylinder for RPV retrieval purposes after the RPV has come to rest. The RPV would then preferably be removed from the net with a hand-operated hoist.

To reposition the high-net recovery system to accommodate a shift in wind direction, the diagonal brace that support the stanchions could be mounted on a swivel-type fitting that would allow them to be temporarily folded back over the truck. Then after raising the jack-screw foot pad at the bottom of each stanchion, the truck could maneuver rapidly to a new heading.

The visual signature of the high-net configuration would relate to a 50-foot high, 36-foot wide rectangle filled in with the net, about 648 square feet, plus the truck envelope including horizontal lines of about 296 square feet.

For transport, the stanchion system would be folded down over the top of the truck in a horizontal position using hand-powered hydraulic jacks where the stanchion tubes would be telescoped to minimum length.

Based on loads resulting from the capture of the 200-pound RPV at 78 knots recovery speed, the maximum cross-sectional dimensions of the tubular aluminum alloy stanchions is 11-1/4-inch diameter with 1/4-inch wall thickness.

The total weight of the high-net system is estimated at 2700-pounds.

Cost estimates for high-net system are:

• Non-recurring	$ 93,000
• Mfg. first unit	$ 51,000
• Quantity of 10 units	$ 470,000
• Quantity of 50 units	$1,921,000

b. Conclusions

Essentially the same statements for the traveling net under subsection 9.3.2 b would apply here. Additional remarks are:

The high-net version of the traveling net family employs one truck versus two trucks for the traveling net system of subsection 9.3.2, which, in itself, is desirable from the points of view of logistics, rigging, and repositioning for wind changes.

However, the net retraction mechanism added to the energy-absorber system, and the addition of a pneumatic power cylinder would most probably lower the high-net's recovery reliability factor under that of the two-truck traveling net system.

A compressed air supply is required for the pneumatic retract cylinder. Compressed air could be supplied directly by a truck equipped with a pneumatic launcher, from air bottles, or from an autonomous compressor system installed on the recovery truck. Direct supply by a launcher truck would add another object to the recovery operations visual signature.

11.3.3 Modified High-Net Recovery System, Concept II-1B-2

a. General

The modified high-net version of the traveling net concept is shown mounted on one M-135 truck in Figure 96 (a) and (b). This net system incorporates a more effective line retraction system and adds a landing net approximately 16 feet wide, which limits the RPV's swing-back angle. The effects of these two features permit reducing the height of the net support stanchions from 50 to 35 feet.

The net and rotary hydraulic energy-absorber system is modified to incorporate a nylon tape and retraction reel driven by the energy absorber. This system is shown schematically in Figure 96 (c).

As the RPV travels with the capture net during the energy-absorber line's payout, the nylon retraction tape is reeled up on the retraction reel, which is driven by the energy absorber shaft. At the end of the arresting stroke, the retraction cylinder is actuated and pulls back on the low-line-raising pulley and also the four corners of the net.

During the descent of the RPV, the pendulum length reduces from 45 feet to 30 feet, or 33 percent, under the action of the retraction system. At the end of its down-swing, the RPV impacts the landing net at a velocity of about 45 feet/second for the 200-pound class RPV. The arresting stroke for the landing net, not to exceed 12 g along the RPV's vertical axis, is estimated to be 3 to 4 feet depending on the method of load attenuation employed.

The RPV could be lowered to the ground or onto a handling fixture for retrieval by releasing the pressure in the pneumatic retract cylinder.

The modified high-net recovery system could be repositioned for shifting wind conditions in generally the same manner as for the high-net as described in subsection 11.3.2 a ahead. However, the additional handling

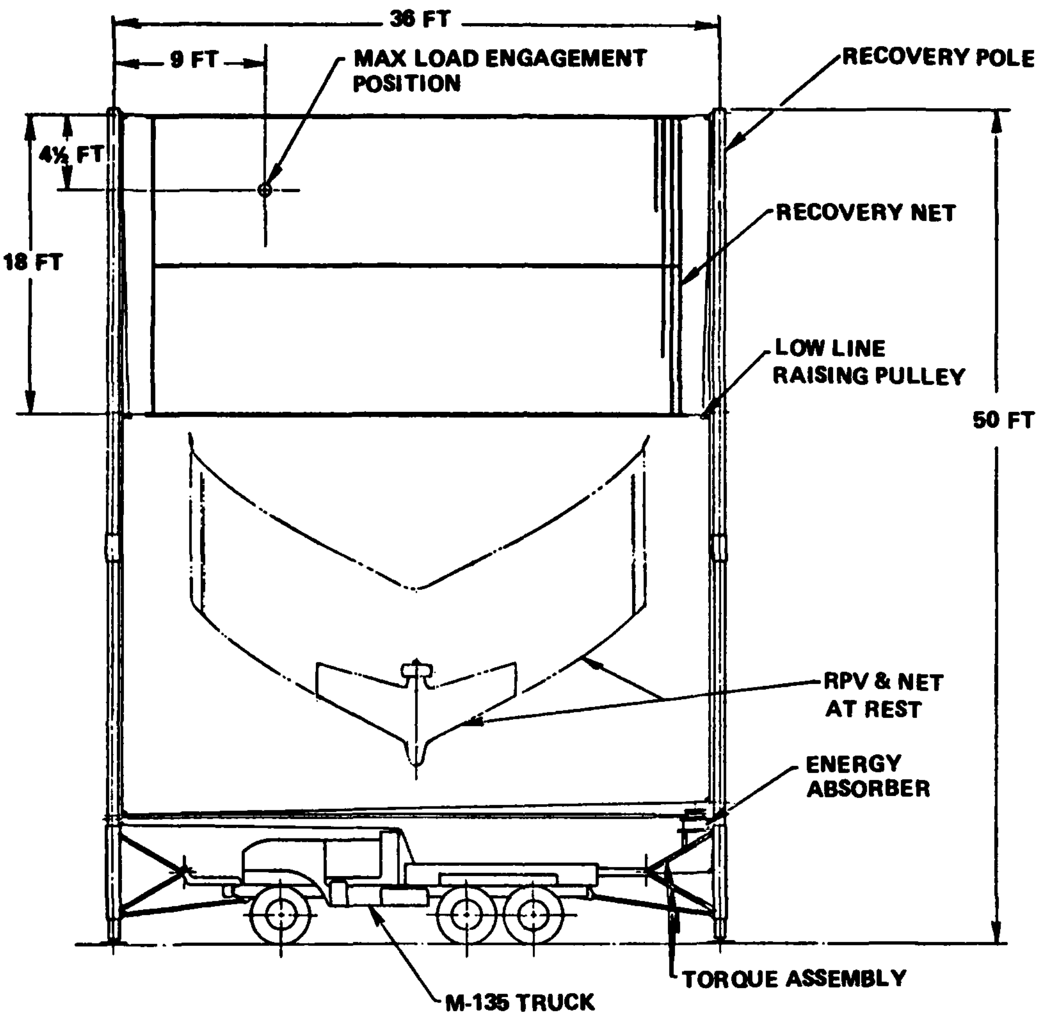

Figure 95(a). Front View, High-Net Recovery System

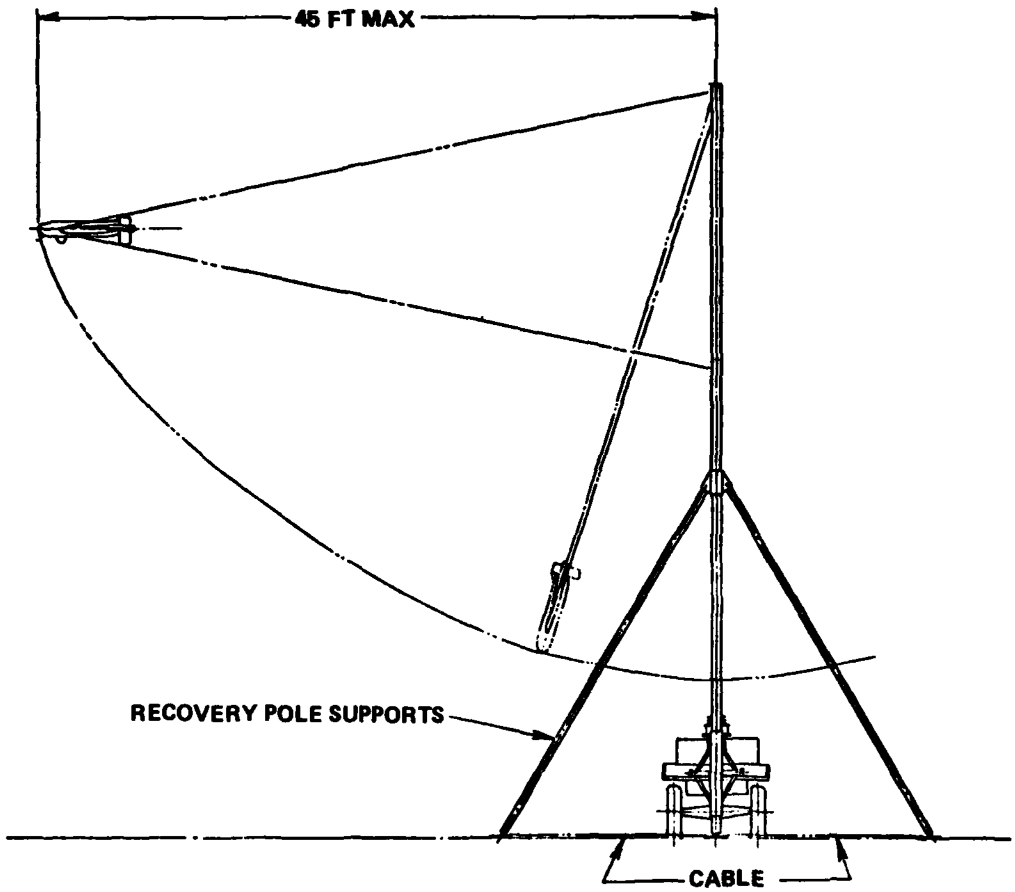

Figure 95(b). Side View, High-Net Recovery System

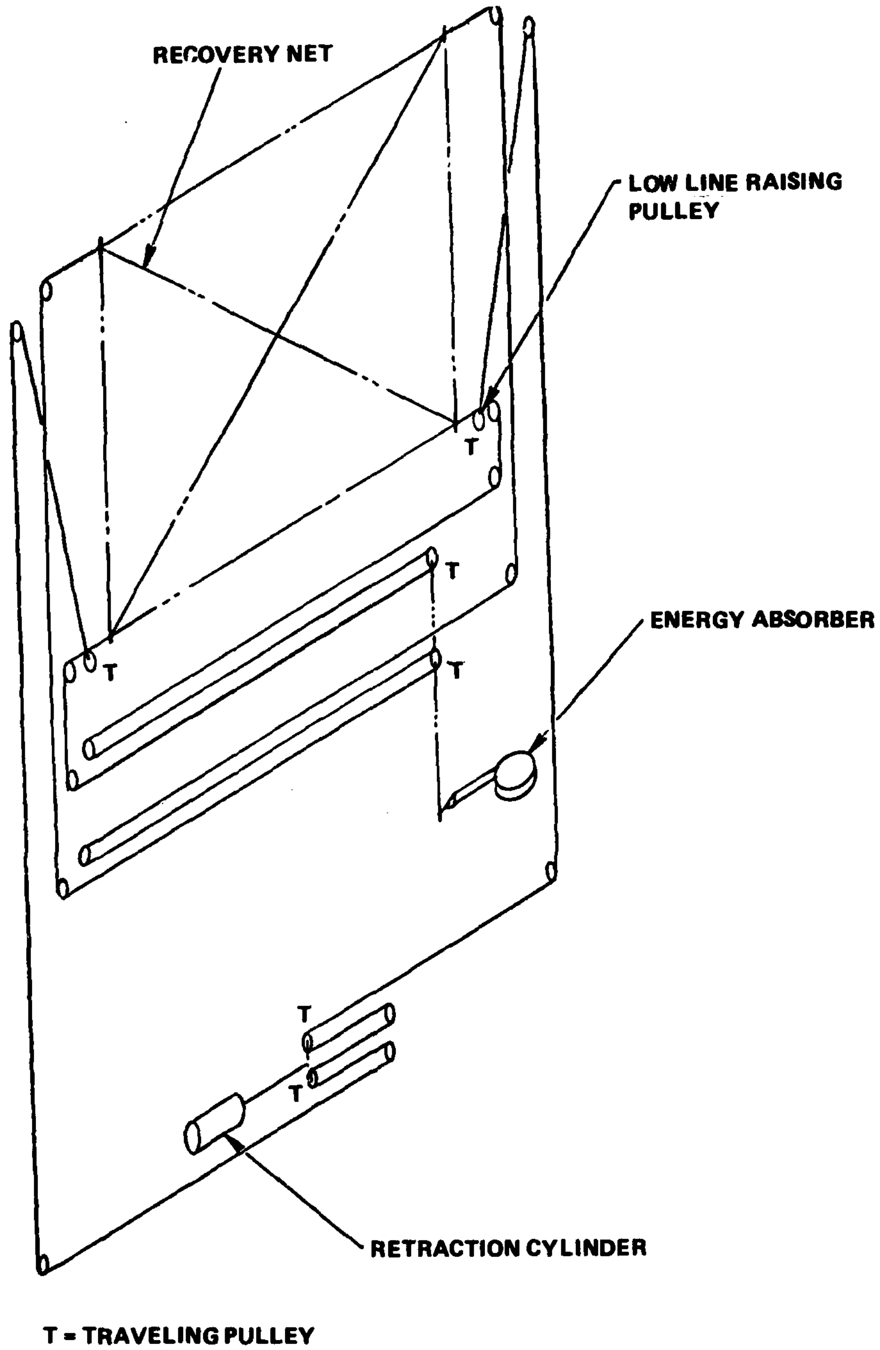

Figure 95(c). Reeve Schematic, High-Net Recovery System required for the landing net would complicate the ing procedure and require more time to complete the move.

The landing net installation would necessitate the use of horizontal spacer members or other provisions to keep the diagonal supports (Figure 96 (b)) from pulling together when the landing net is impacted by the RPV.

Without detailed study on the subject, it is impossible to satisfactorily compare the visual signature of the modified high-net with a similar system like the high-net. However, the modified high-net does present a more solid object to view, since the two nets essentially fill in the rectangular area formed by the maximum dimensions of the system as seen in the full front view ($35 \times 36 = 1260$ ft^2).

Transport procedures would be similar to that for the high-net except for handling and stowing any additional members occasioned by the landing net.

The maximum cross-sectional dimensions of the tubular aluminum alloy stanchions is estimated at 8-1/2-inch diameter with 1/4-inch wall thickness. Total weight of the modified high-net system is estimated at 1800 pounds.

Cost estimates for the modified high-net system are:

- Nonrecurring $ 95,000
- Mfg. First Unit $ 51,000
- Quantity of 10 Units $ 474,000
- Quantity of 50 Units $1,941,000

b. Conclusions

Essentially the same statements for the traveling net presented in subsection 9.3.2 b would apply here. Additional remarks are:

The modified high-net recovery system would lower the overall reliability level under that of the high-net's in that the main net retraction system is appreciably more complex, and a landing net, with its energy-absorbing requirements is added.

A compressed air supply (discussed in 11.3.2 b) would also be required for the modified high-net system.

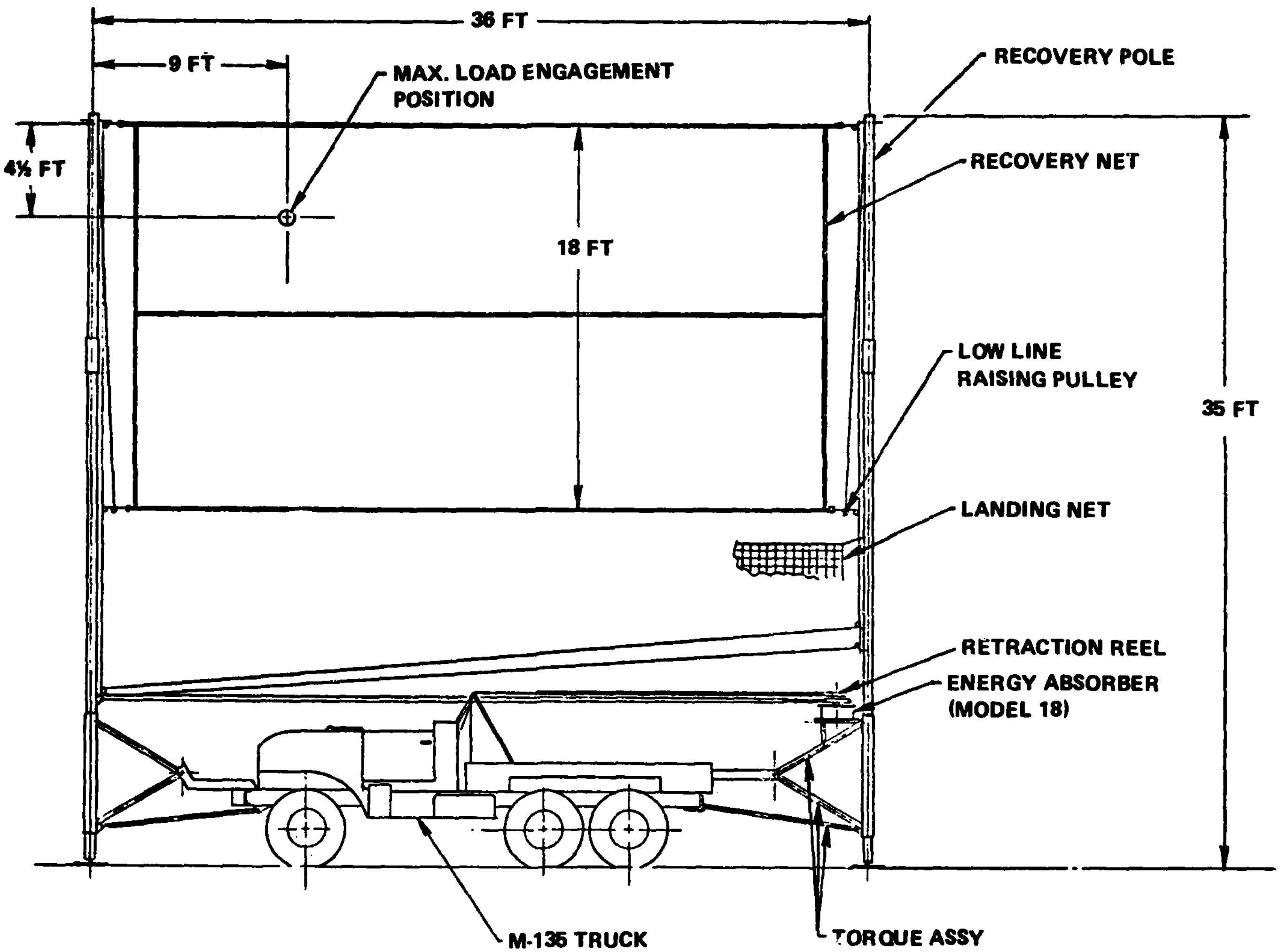

Figure 96(a). Front View, Modified High-Net Recovery System

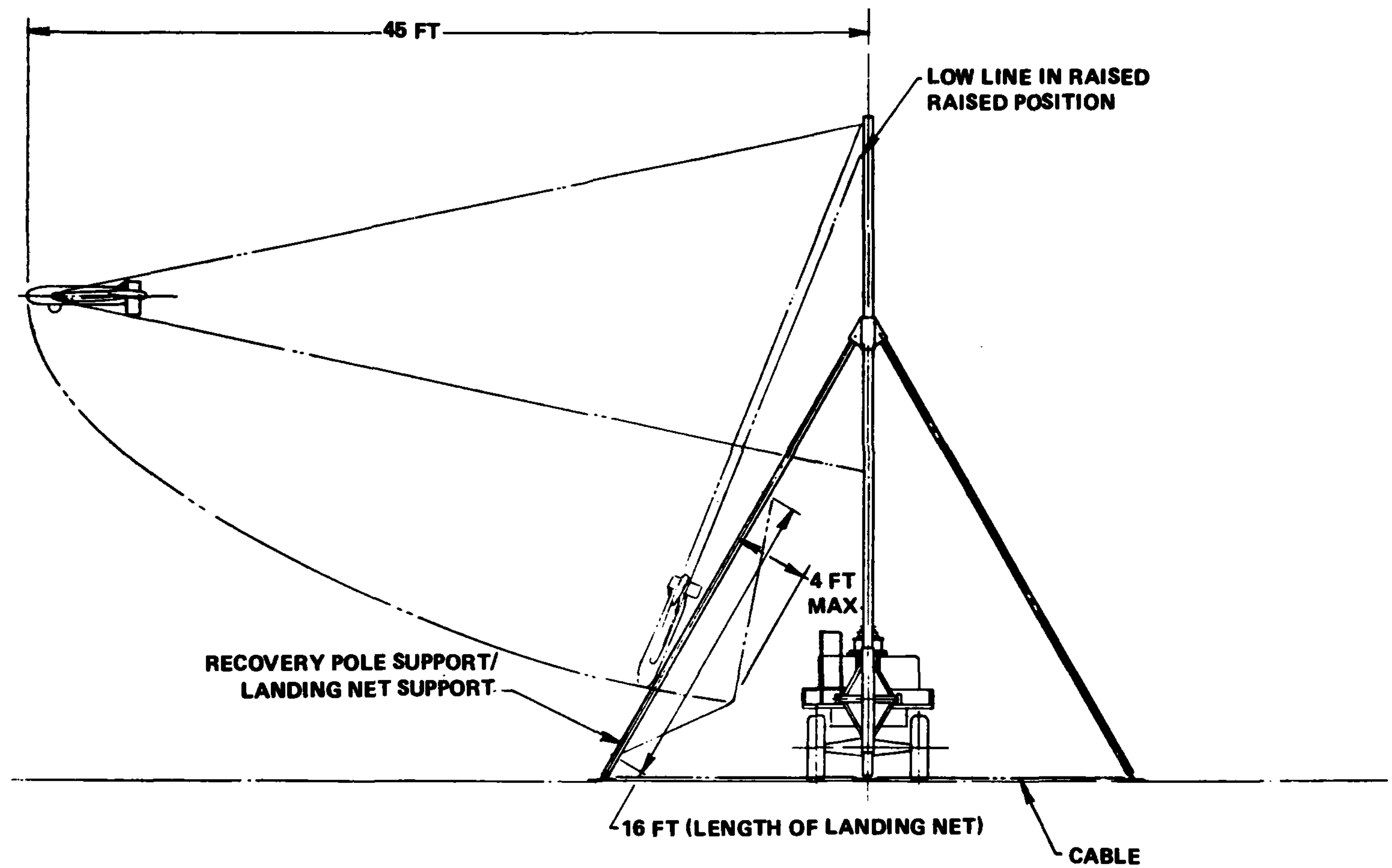

Figure 96(b). Side View, Modified High-Net Recovery System

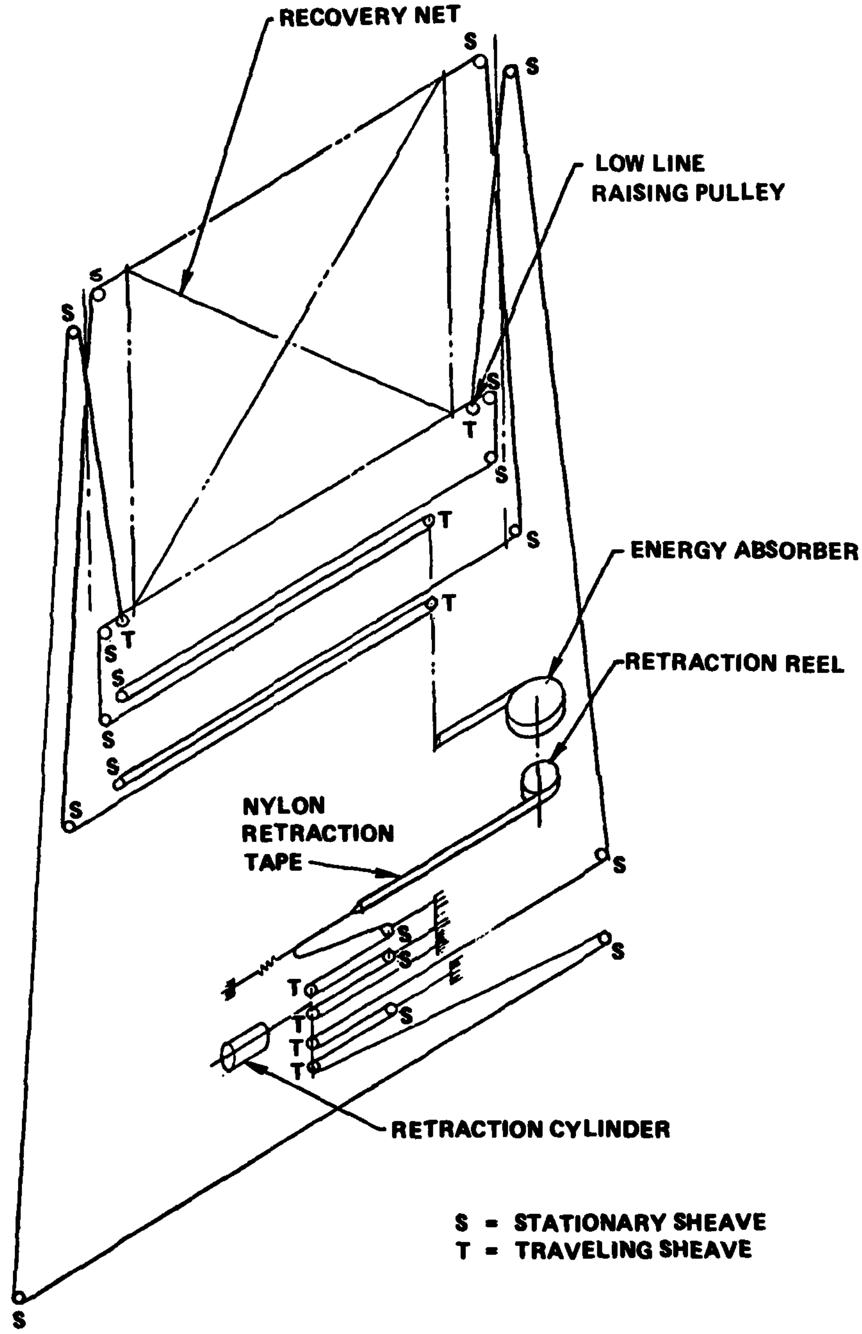

Figure 96(c). Reeve System Schematic, Modified High-Net System

11.3.4 Low-Net/Air Inflated Platform, Concept II-1C-1

a. General

The low-net/air inflated platform (Figure 97(a) and (b)) is seen to be essentially the same concept as the air mat version of the traveling net plus impact platform, Concept II-c, discussed in subsection 9.3.3 and shown in Figure 83. Differences occur in that the total height of the net stanchions for the low-net/air inflated platform recovery system is 28 feet as against 31 feet for the basic concept; and a smaller, denser (about 0.11 versus 0.023 pounds/foot^2) air mat is used. A proposed air bag is 30 x 30 x 4 feet (= 3600 feet^3) made of HI-TUFF .020-inch polyurethane, inflated to a pressure equivalent to 11.5-inches of water (about 60 psf).

The energy-absorbing system for the low-net system is based on dual 12-inch diameter rotary hydraulic energy absorbers, which provide retarding forces applied to all four corners of the capture net during the 45-foot deceleration stroke. The air bag's rated capability, based on recovery of a 200-pound RPV with a total plan view area of 40 feet, is 12g maximum at a maximum drop height of 25 feet.

Reference is made here to subsection 9.3.3 a, for discussion on general aspects of erecting, handling, and retrieving the RPV as related to the air mat system.

The visual signature of the low-net/air inflated platform, enhanced somewhat by the presence of the air mat, would otherwise present less vertical area (1007 square feet) than the modified high net at 1260 square feet.

Transport provisions for the low-net/air mat concept would be accomplished by folding the stanchions over the top of the M-135 truck as indicated in Figure 83. The polyurethane air mat can be stowed in a 3 by 3 by 6 foot container.

The maximum cross-sectional dimensions of the stanchions are the same as for the modified high-net, Section 11.3.3 a, at 8-1/2-inch diameter with 1/4-inch wall thickness.

Total weight of the system is estimated at 1900 pounds.

Cost estimates for the low-net/air inflated platform system are:

•	Nonrecurring	$ 86,000
•	Mfg. First Unit	$ 75,000
•	Quantity of 10 Units	$ 604,000
•	Quantity of 50 Units	$2,545,000

b. <u>Conclusions</u>

Essentially the same statements for the traveling net impact platform under subsection 9.3.3 b, as pertinent to the air mat concepts, would apply here. Additional remarks are:

The low-net/air mat system is simpler than either of the preceding concepts involving net retraction mechanisms. Both the energy-absorption system and the air mat impact platform have general credibility established by test hardware (subsection 7.6.4).

Since stakes or other means of attaching tie-downs to the ground are generally undesirable, a system of weights or other means of securing the air mat should be considered.

The estimate of nonrecurring costs for the air mat concept are 7-1/2 to 9-1/2 percent less, but the unit cost for quantities of 50 each, due to the air mat cost, is 31 to 32-1/2 percent greater than for the nets with retract systems.

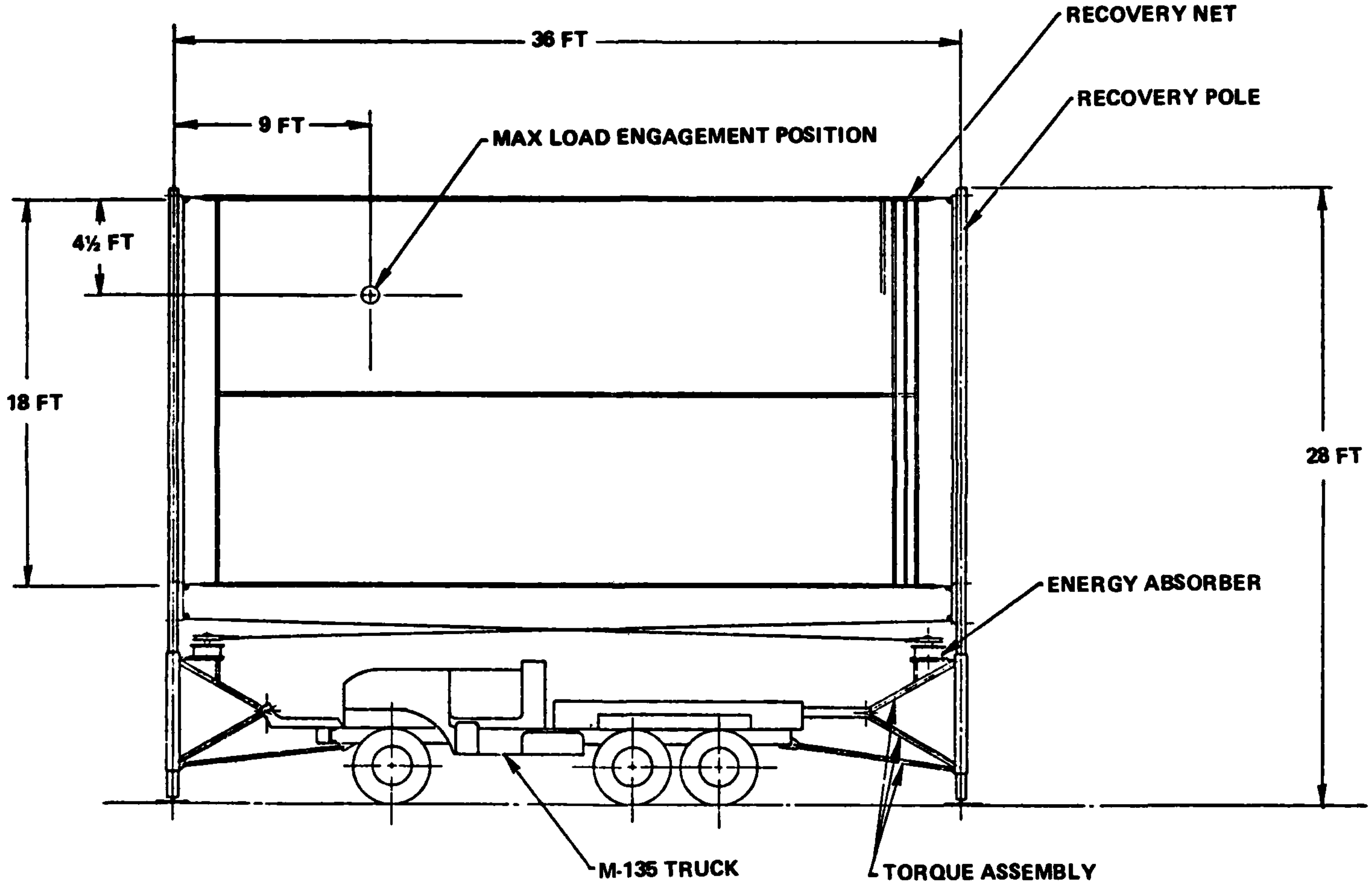

Figure 97(a). Front View, Low-Net/Air Inflated Platform Recovery System

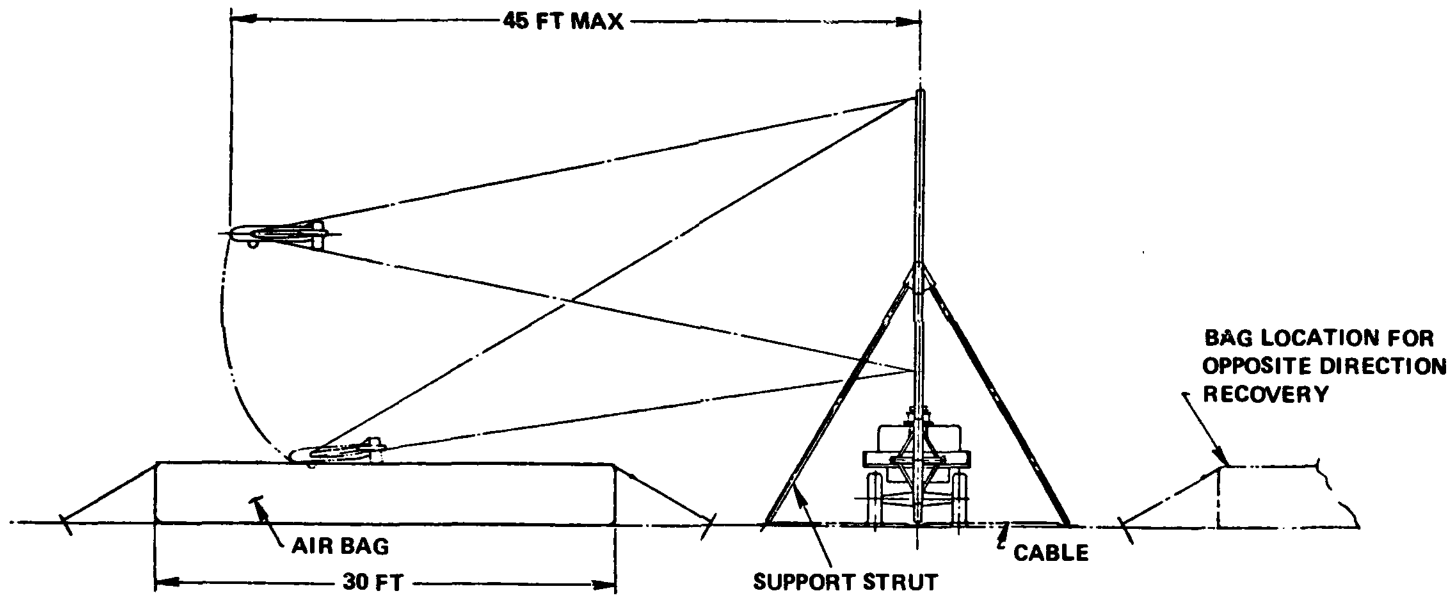

Figure 97(b). Side View, Low-Net/Air Inflated Platform Recovery System

12.0 EVALUATION OF THE PREFERRED SYSTEM

12.1 Introduction

The three recovery concepts studied in Phase III are evaluated in this section to select a preferred system. The concepts are:

Group I - Surface - Impact

- Nongliding Chute, Concept I-2A

Group II - Above Surface Recovery

- Traveling Net, Concept II-1B
  (High-Net Recovery System, Concept II-1B-1)
  (Modified High-Net Recovery System, Concept II-1B-1)
- Traveling Net Impact Platform, Concept II-1B
  (Low-Net/Air Inflated Platform, Concept II-1C-1)

For purposes of evaluating the traveling net family, Concepts II-1B-1, II-1B-2, and II-1C-1 are considered to be candidates. However, within the limits of accuracy of the available data and the evaluation process, the distinctions that can be made between the two high-net recovery types appears to be insignificant in terms of the overall results. It will be noted, too, that the cost estimates for the two high-nets are not appreciably different. Therefore, the designation "traveling net" in the following evaluation tabulations represents a composite of Concepts II-1B-1 and II-1B-2.

12.2 Evaluation Summary

Results of the evaluation are shown graphically in Figure 98. The parachute recovery system comes out on top. This system is the cheapest to procure, and is generally a better operational and tactical system than either of the other two (see Table 18). However, the parachute recovery system impacts the design of the RPV very severely, and is more expensive to operate. Figure 99 shows the cost per recovery for each of the candidate systems. Both the traveling net and the traveling net plus impact platform systems are cheaper to operate in a high-usage scenario. The reason for this is the greater probability of damage to the RPV with the parachute system, and the fact that a single parachute will last for only a few recoveries (three are assumed in this evaluation). The costs depicted in Figure 19 do not include refurbishment of the parachute and its repacking after use. These latter costs will, of course, accentuate the differences in cost of recovery. The actual cost data is shown in Table 19 and an explanation of the derivation of these costs is found in Appendix A. The methodology of the evaluation is identical to that described earlier. In this instance, however, more attention was given to detail, and weights were assigned to second-level as well as first-level items (see Table A-1).

Table A-2 presents data on which this evaluation was performed. Table A-3 presents the raw scores of these data (10 high - 0 low). Table A-1 presents a matrix explaining how the 55 individual items were scored. As before, the undesirable bias inherent in the development of the items to be scored was taken out by adjusting the scores so that every second-level item was weighted equally within a first-level group; and each of the first-level groups was weighted equally. This "adjusted" score is presented in Table A-4.

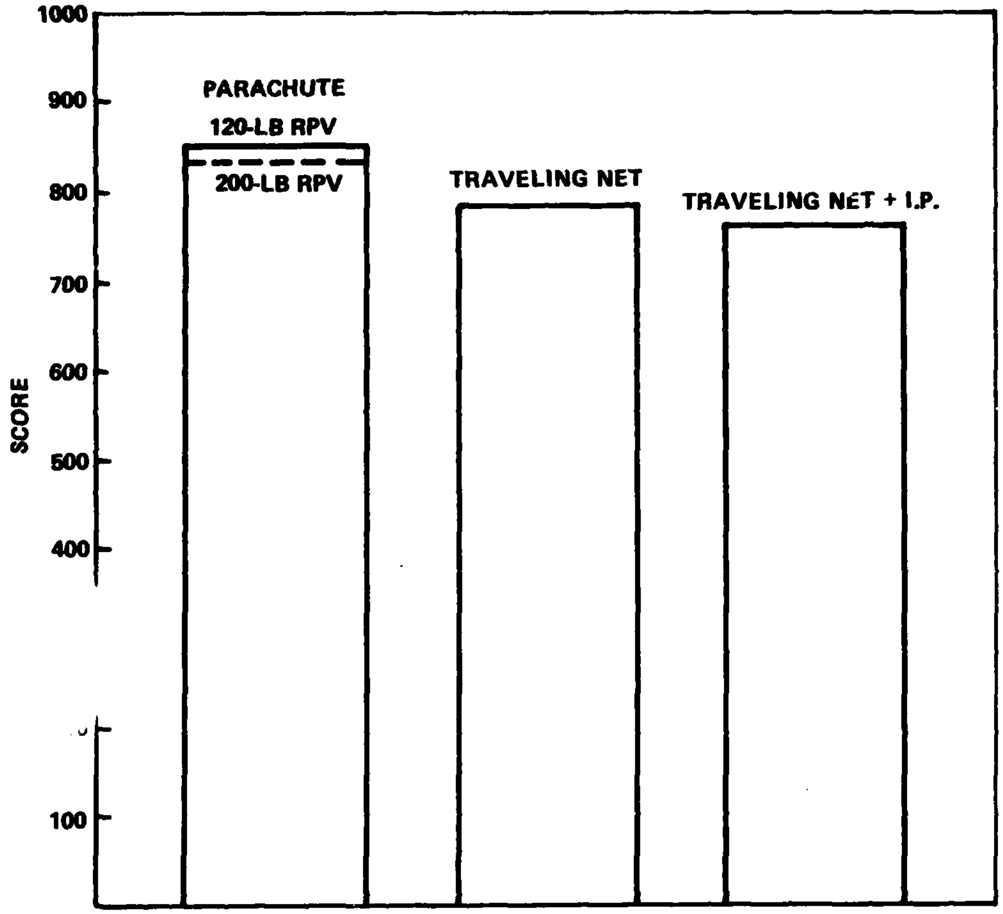

Figure 98. Evaluation Results, Preferred Reccvery System

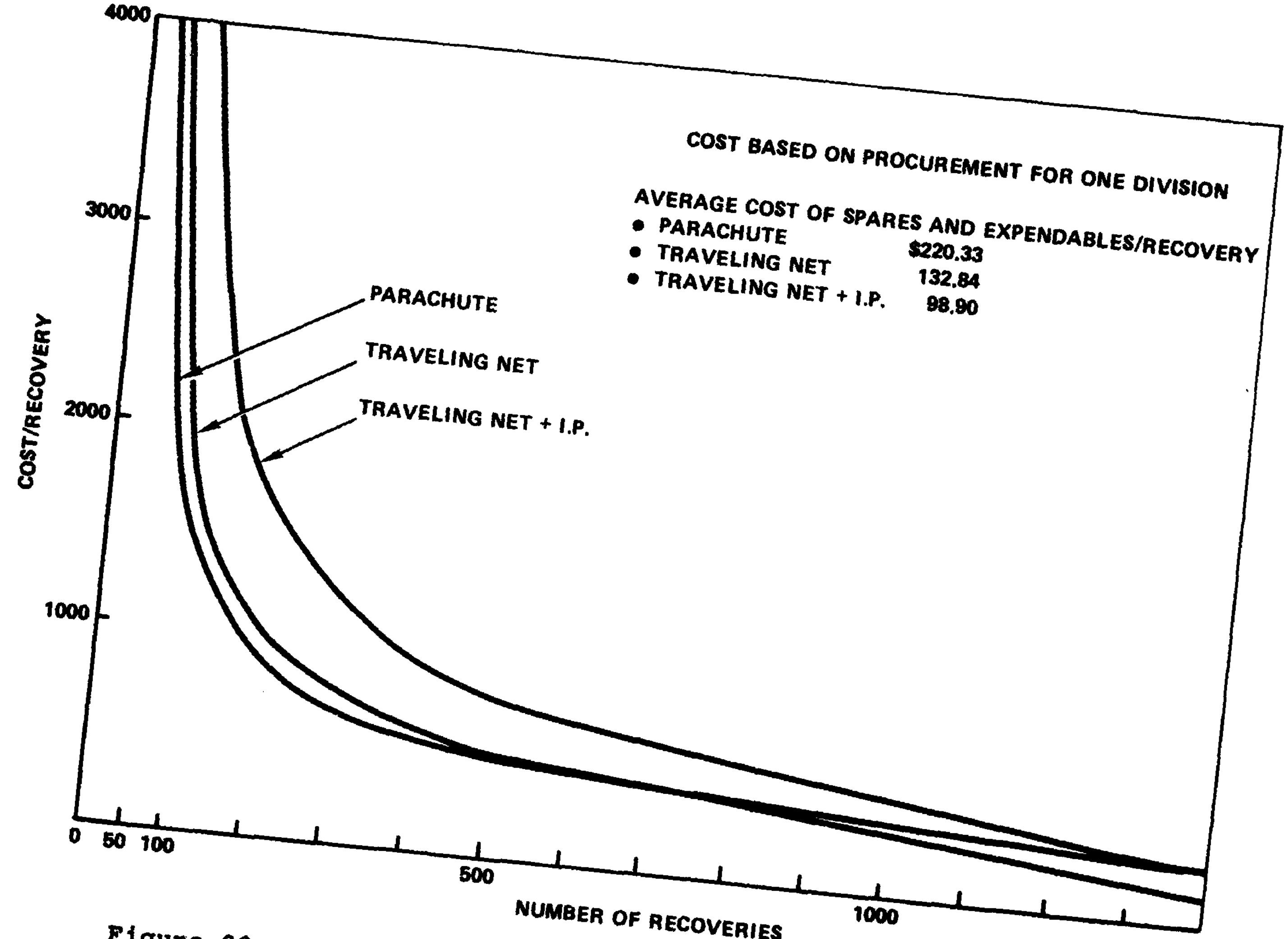

Figure 99. Cost per Recovery versus Number of Recoveries

TABLE 18. WEIGHTED SCORE

Item No.	Evaluation Parameter	Weight	Group I	Group II	
			Parachute	Traveling Net	Traveling Net + I. P.
	TOTAL SYSTEM	1,000	852.36/830.59	788.76/787.62	761.06/559.95
1.0	Accommodation by Mini-RPV	250	193.03/177.19	230.73/229.74	230.73/229.74
1.1	Physical Parameters	125	99.55/83.43	123.44/122.45	123.44/122.45
1.2	Operational Parameters	65	55.44	52.39	52.39
1.3	Tactical Parameters	60	38.06/38.32	54.90	54.90
2.0	Adaptability to Field Employment	200	180.22	135.42	120.85
2.1	Physical Parameters	50	46.78	21.49	17.40
2.2	Operational Parameters	50	48.48	40.98	34.48
2.3	Tactical Parameters	100	84.96	72.95	68.97
3.0	Serviceability of Recovery Operations	150	135.85	121.58	118.71
3.1	Physical Parameters	35	35.00	27.88	27.88
3.2	Operational Parameters	75	66.75	59.91	59.78
3.3	Tactical Parameters	40	34.10	33.79	31.05
4.0	Suitability for Subdivisional Army Integration	150	133.31	101.51	100.58
4.1	Physical Parameters	40	37.48	25.88	26.77
4.2	Operational Parameters	75	64.48	64.48	56.98
4.3	Tactical Parameters	35	31.35	21.15	16.83
5.0	Cost and Risk	250	219.95/214.02	199.52/199.37	190.19/190.07
5.1	Development Cost	25	16.27/15.07	19.02/18.87	18.20/18.08
5.2	Procurement Cost	75	71.07/15.07	67.80	65.48
5.3	Life Cycle Cost (10 yr per Div)	100	85.28/82.62	72.98	69.68
5.4	Risk	50	47.33	39.72	26.83

TABLE 19. COST DATA

Evaluation Parameter	Group I	Group II	
	Parachute	Traveling Net	Traveling Net + I. P.
COST AND RISK			
Development Cost	6985/7945	93144/93240	106144/101240
Air Vehicle Equipment	6985/7945	144/240	144/240
Ground Equipment	-0-	93 000	106, 000
Production Cost	1054/1601	38, 420	50. 900
Air Vehicle (Unit/1000 Production)	1054/1601	0	0
Ground Equipment (Unit/50 Production)	0	38, 420	50, 900
Life Cycle Cost (10 yr per Division)	283449/335228	400979/401070	446805/446901
Development Cost	6985/7945	93144/93240	106144/106240
Procurement Costs	119648/152779	202, 621	262, 333
Recovery System	26350/40025	192, 100	254 ,500
Initial Spares	93248/112754	10, 521	7 833
Support Costs	156816/174504	105, 209	78, 328

NOTE: See Appendix A for explanation of items in this Table and Item 5.0 on Table A-2.

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APPENDIX A

PREFERRED SYSTEM EVALUATION DATA INPUTS

Table A-1. RAW SCORES AND DATA MATRIX

1.1.1.1 Weight Airborne on RPV
Weights in pounds. The first number is for the 120 pound RPV, the second number for the 200 pound RPV. Data based on conceptual analysis.

$$\text{SCORE} = 10 - \frac{\text{Weight}}{2}$$

1.1.1.2 Volume Airborne on RPV
Volume in ft^3. The first number is for the 120 pound RPV, the second number for the 200 pound RPV. Data based on conceptual analysis. SCORE = 10 (1-volume).

1.1.1.3 Power Requirements on RPV
Power in watts. Data based on conceptual analysis. Very little power requirement on all systems. SCORE = 10.

1.1.2 Impact on RPV Design
SCORE = Average score of 1.1.1.1, 1.1.1.2, and 1.1.1.3.

1.2.1 Guidance and Control Accuracy
Data is terminal window for RPV (ft^2). Data based on conceptual analysis. SCORE = $\ln$ (WINDOW) ≤ 10.

1.2.2 Vehicle Dynamic Response Numbers represent radians per second normalized to 100 feet from recovery impact. SCORE = 10 (1-N).

1.2.3 Probability of Successful Recovery
Data based on conceptual analysis. SCORE = 10P.

1.2.4 All Weather Potential
Ice may adversely affect the traveling net. Score based on engineering judgement.

1.2.5.1 MTBF of Airborne System
MTBF in hours. Data based on engineering pre-design for comparable systems.

$$\text{SCORE} = \frac{\text{MTBF}}{10}.$$

1.2.5.2 MTTR of Airborne System

MTTR in hours. Data based on engineering predesign for comparable systems. SCORE = 10-2 (MTTR).

1.3.1 RPV Approach to Recovery Site Restrictions. Score based on engineering judgements.

1.3.2 Airborne Recovery Signature
Time in seconds from start of recovery operation until its end. Area of parachute in ft^2. Data based on conceptual analysis.

$$\text{SCORE} = \frac{\text{Time X Area}}{100}$$

1.3.3 Mission Interface Restrictions
The larger the airborne recovery components the less mission equipment the RPV can carry.

$$\text{SCORE} = 10 \left(1-10 \text{ X } \frac{\text{Weight of Airborne Recov. Components}}{\text{Gross Wt of RPV}}\right).$$

2.1.1.1 Set-up Height of Recovery Components
Values are in feet. Data based on preliminary design analysis.

$$\text{SCORE} = 10 - \frac{\text{Height}}{.5} \geq 0.$$

2.1.1.2 Set-up Width of Recovery Components
Values are in feet. Data based on preliminary design analysis.

$$\text{SCORE} = 10 - \frac{\text{Width}}{5} \geq 0.$$

2.1.2 Minimum Recovery Site Area
Values are in ft^2. Data based on conceptual analysis.

$$\text{SCORE} = 10 \left(1- \frac{\text{Radius of Area in Meters}}{150}\right).$$

2.1.3 Edge Obstruction Height
Values are in feet. Data based on conceptual analysis. All systems meet requirements. SCORE = 10.

2.2.1 Crew Size
Data based on conceptual analysis. SCORE = 11-N.

2.2.2 Crew Skill

Score based on engineering judgement.

2.2.3 Component Transportability
Values are number of M-135 trucks or equivalent required for transportation. Data based on preliminary design. SCORE = 10.5-2N.

2.2.4 Site Preparation Time
Values are in minutes. Data based on conceptual analysis.

$$SCORE = 10(1 - \frac{Time}{60}).$$

2.2.5 Geological/Geographical Constraint
Values are maximum topographic gradient in degrees. Data based on conceptual analysis. SCORE = 10

$$(1-\frac{Slope}{10}).$$

2.3.1 Time to Set up
Values are in minutes. Data based on conceptual analysis. SCORE = 10 - $\frac{Time}{5}$.

2.3.2 Time to Dismantle
Values are in minutes. Data based on conceptual analysis.

$$SCORE = 10 - \frac{Time}{5}.$$

2.3.3 Detectability
Detection of the recovery site as a recovery area is most likely determined by observing airborne recovery signatures. SCORE = 1.3.2 SCORE.

2.3.4 Concealment
The larger the recovery system, and the more vehicle required for transport, the more difficult is concealment. SCORE = AVERAGE SCORE OF 2.1.1.1, 2.1.1.2, and 2.2.3.

2.3.5 World Wide Operations
Score based on engineering judgement.

3.1.1.1 Approach Window Size Height
Values are in feet. Data based on conceptual analysis. SCORE = 5 log HEIGHT $\leq$10.

3.1.1.2 Approach Window Size Width
Values are in feet. Data based on conceptual analysis. SCORE = 5 log WIDTH ≤ 10.

3.1.2 Approach Angle Limit
Values are approach window in degrees. Data based on conceptual analysis. SCORE = 5 log ANGLE ≤ 10.

3.1.3 Time to Reorient for Wind Shift
Values are in minutes. Data based on conceptual analysis. SCORE based on engineering judgement.

3.2.1 Automatic/Manned Recovery Operation
SCORE based on engineering judgement.

3.2.2 Probability of Recovery Without Damage
Data is based on conceptual analysis. SCORE = 10P.

3.2.3 Time to Retrieve RPV and Reset Recovery System
Values are in minutes. Data based on conceptual analysis.

$$\text{SCORE} = 10 \frac{5}{\text{Time}}.$$

3.2.4 Guidance and Control Accuracy
Values are the terminal window area in ft^2. Data based on conceptual analysis. Score based on engineering judgement.

3.2.5.1 MTBF of Recovery System
Values are in hours. Data based on conceptual analysis.

$$\text{SCORE} = \frac{\text{MTBF}}{100} \leq 10.$$

3.2.5.2 MTTR of Recovery System
Values are in hours. Data based on conceptual analysis. SCORE = 10-2 (MTTR).

3.2.5.3 Availability of Recovery System

Values are $\frac{\text{MTBF}}{\text{MTBF+MTTR}}$. SCORE = 10 (AVAILABILITY).

3.3.1 All Weather Potential
Scores based on engineering judgement.

3.3.2 Access for Retrieval
Scores based on engineering judgement.

3.3.3 Mission Interface Restrictions
Restrictions to mission operations are affected by site preparation times, geological/geophysical constraints and the time to set-up and dismantle the system. SCORE = AVERAGE of 2.2.4 SCORE, 2.2.5 SCORE, 2.3.1 SCORE, and 2.3.2 SCORE.

3.3.4 Unusual Recovery Signatures
Score the same as 1.3.2, Airborne Recovery Signature.

4.1.1 Reduced Dimensions for Transportation
Values are in ft^3. Data from preliminary design analysis.

$$SCORE = 10-\frac{Vol}{25}.$$

4.1.2 Packaged Weight
Values are in pounds. Data from preliminary design analysis.

$$SCORE = 10 - \frac{Weight}{1200}$$

4.1.3.1 Truck Modification Cost
Score based on engineering estimates.

4.1.3.2 Number of Trucks
Values are equivalent M-135 truck data based on conceptual analysis. SCORE = 10.5-2N.

4.2.1 Crew Size
Values are minimum number of personnel required. Data based on conceptual analysis. SCORE = $10-N \geq 0$

4.2.2 Self Mobility
All systems are self mobile. SCORE = 10.

4.2.3 Run-for-Cover Capability
Ability to run-for-cover affected by time to dismantle the system. SCORE = same as 2.3.2.

4.2.4 Logistic compatibility
The parachute system requires more expendable items (the parachute) than does the other system. Score based on engineering estimates.

4.2.5 Complexity of Operation
Score based on engineering estimates.

4.3.1 Safety
Score based on engineering estimates.

4.3.2 Concealment
Score the same as 2.3.4. See that item for comments.

4.3.3 Time to Run for Cover
Values are in minutes. Data based on conceptual analysis.

$$\text{SCORE} = 10 \frac{5}{\text{Time}}$$

4.3.4 Mission Interface Restrictions
Score same as 3.3.3.

5.1 Development Cost
Air vehicle cost includes parachute data from Pioneer Parachute Company plus $200 per pound estimate for additional RPV cost. Ground equipment cost data from All American Engineering Company. The first number is for the 120 pound RPV; the second number's for the 200 pound RPV.

$$\text{SCORE} = 10 - \frac{\text{Cost}}{1000} \quad \text{for the Air Vehicle.}$$

$$\text{SCORE} = 10 - \frac{\text{Cost}}{20000} \text{ for Ground Equipment.}$$

5.2 Procurement Costs
Air vehicle include parachute plus $100 per pound estimate for additional RPV cost. Basic RPV can perform the net recovery. The first number is for the 120 pound RPV, the second number is for the 200 lb. RPV. Parachute data from Pioneer Parachute Company. Net data from All American Engineering Company.

$$\text{SCORE} = 10 - \frac{\text{Cost}}{1000} \text{ for air vehicle.}$$

$$\text{SCORE} = 10 - \frac{\text{Cost}}{20000} \text{ for ground equipment.}$$

5.3 10 Year Life Cycle Cost
Procurement costs assume 25 RPVs per division (5 RPVs per section). Support costs are based on 36 training flights per year per division, plus thirty six (36) flights per week per division, for a 12-week war. Parachutes are assumed replaced after 3 flights. Initial spares are the cost of 5 parachutes per RPV plus 10% of total spares. Total spares are based on $1000 repair cost per RPV damaged on recovery as per item 3.2.2 plus net

recovery replacement as per the MTBF (item 3.2.5.1). Support cost include replacement parachute and spares only.

$$\text{SCORE} = 10 - \frac{\text{Cost}}{20000} \text{ development costs}$$

$$= 10 - \frac{\text{Cost}}{50000} \text{ other costs}$$

5.4.1 Probability of Successful Demonstration
Score based on engineering estimate.

5.4.2 Probability of Meeting Costs
Score based on engineering estimates.

5.4.3 Probability of Survival 2-5 km from FEBA
This is a function of detectability, concealment, and time to run for cover. SCORE = AVERAGE of 2.5.3 SCORE, 2.3.4 SCORE, and 4.3.3 SCORE.

TABLE A-2. RAW DATA

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
1.0	ACCOMMODATION BY MINI-RPV			
1.1	Physical Parameters			
1.1.1	Airborne Recovery Components			
1.1.1.1	Weight (lbs)	7.6-12.4	0.72-1.2	0.72-1.2
1.1.1.2	Volume	.23 - .377	0	0
1.1.1.3	Power	0	0	0
1.1.2	Impact on RPV Design			
1.2	Operational Parameters			
1.2.1	Guidance and Control Accuracy	40,000	24	24
1.2.2	Vehicle Dynamic Response	0	0.08	0.08
1.2.3	Probability of Successful Recovery	0.97	0.95	0.95
1.2.4	All Weather Potential	Yes	Ice	Ice
1.2.5	Reliability and Maintainability			
1.2.5.1	MTBF	250	900	900
1.2.5.2	MTTR	0.5	0.75	0.75
1.3	Tactical Parameters			
1.3.1	RPV Approach to Recovery site Restrictions	None	Into wind	Into wind
1.3.2	Airborne Recovery Signature	9 sec-51.5 ft^2	3.76 sec-25 ft^2	3.76 sec-25 ft^2
1.3.3	Mission Interface Restrictions	Average (1.1.1.1 + 1.1.1.2 + 1.1.1.3)		

TABLE A-2. (Continued)

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
2.0	ADAPTABILITY TO FIELD EMPLOYMENT			
2.1	Physical Parameters			
2.1.1	Setup Size of Components			
2.1.1.1	Height	-0-	50 ft.	28 ft.
2.1.1.2	Width	-0-	36 ft.	36 ft.
2.1.2	Recovery Site Area (Minimum)	50,000 sq. ft	239,000 sq. ft	244,000 sq ft
2.1.3	Edge Obstruction Height (Maximum)	50 ft.	35 ft.	15 ft.
2.2	Operational Parameters			
2.2.1	Crew Size	2	3	3
2.2.2	Crew Skills	.5	1.5	2
2.2.3	Component Transportability			
2.2.4	Site Pre-Preparation Time	0	15 min	30 min
2.2.5	Geological/Geographical Constraints	10° slope	10° slope	3° slope
2.3	Tactical Parameters			
2.3.1	Time to Setup	5 min	10 min	30 min
2.3.2	Time to Dismantle	0	10 min	30 min
2.3.3	Detectability			
2.3.4	Concealment			
2.3.5	World Wide Operations			

TABLE A-2. (Continued)

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
3.0	SERVICEABILITY OF RECOVERY OPERATIONS			
3.1	Physical Parameters			
3.1.1	Approach Window Size			
3.1.1.1	Height	100	50	50
3.1.1.2	Width	400	50	50
3.1.2	Approach Angle Limit	36^{o}	8	8
3.1.3	Time to Reorient for Wind Shift	0	10	10
3.2	Operational Parameters			
3.2.1	Automatic/Manual Recovery Operations	Automatic	Semi-Auto	Semi-Auto
3.2.2	Probability of Recovery w/o Damage	.900	.944	.962
3.2.3	Time to Retrieve RPV and reset Recovery System	15	5	10
3.2.4	Guidance and Control Accuracy Reqmts	40,000 ft^2	24 ft^2	24 ft^2
3.2.5	Reliability and Maintainability			
3.2.5.1	MTBF		500	1,000
3.2.5.2	MTTR	0	1	2
3.2.5.3	Availability	1	.998	.998
3.3	Tactical Parameters			
3.3.1	All Weather Potential	Excellent	Good	Good
3.3.2	Access for Retrieval			
3.3.3	Mission Interface Restrictions			
3.3.4	Unusual Recovery Signatures			

TABLE A-2. (Continued)

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
4.0	SUITABILITY FOR SUBDIVISIONAL ARMY INTEGRATION			
4.1	Physical Parameters			
4.1.1	Reduced Dimensions for Transportation	25 est	184	145
4.1.2	Packaged Weight	12 est	2700	2300
4.1.3	M-135 Cargo Truck Compatibility			
4.1.3.1	Truck Modification Cost	-0-	---	---
4.1.3.2	Number of Trucks	0.5	1.5	2
4.2	Operational Parameters			
4.2.1	Crew Size	2	3	3
4.2.2	Self-Mobility	Yes	Yes	Yes
4.2.3	Run-for-Cover Capability			
4.2.4	Logistic Compatibility			
4.2.5	Complexity of Operations	Simple	Complex	Complex
4.3	Tactical Parameters			
4.3.1	Safety	Very Good	Good	Good
4.3.2	Concealment			
4.3.3	Time to Run for Cover	5	10	30
4.3.4	Mission Interface Restrictions			

TABLE A-2. (Continued)

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
5.0	COST AND RISK			
5.1	Development Cost	6985/7945	93144/93240	106144/101240
5.1.1	Air Vehicle Equipment	6985/7945	144/240	144/240
5.1.2	Ground Equipment	-0-	93,000 (1)	106,000 (1)
5.2	Production Cost	1054/1601	38,420	50,900
5.2.1	Air Vehicle (Unit/1000 Production)	1054/1601	0	0
5.2.2	Ground Equipment (Unit/50 Production)	0	38,420 (2)	50,900 (2)
5.3	Life Cycle Cost (10 yr per Division)	283449/335228	400979/401070	446805/446901
5.3.1	Development Cost	6985/7945	93144/93240	106144/106240
5.3.2	Procurement Costs	119648/152779	202,621	262,333
5.3.2.1	Recovery System	26350/40025	192,100	254,500
5.3.2.2	Initial Spares	93248/112754	10,521	7,833
5.3.3	Support Costs	156816/174504	105,209	78,328
5.4	Risk			
5.4.1	Probability of Successful Demonstration			
5.4.2	Probability of Meeting Cost			
5.4.3	Probability of Survival 2-5 km from FEBA			

(1) Includes M-135 Truck Modification Nonrecurring and Recurrent Costs
(2) Breakout of Truck Modifications, Unit Cost/Truck:
First article, $2,500; Next 10 articles, $2,300; Next 50 articles $1,900

TABLE A-3. RAW SCORE DATA

Item No.	Evaluation Parameter	Group I Parachute	Group II Traveling Net	Group II Traveling Net + I. P.
1.0	Accommodation by Mini-RPV	102.11- 97.08	115.36-115.04	115.36-115.04
1.1	Physical Parameters	31.87- 26.71	39.52- 39.20	39.52- 39.20
1.1.1	Airborne Recovery Components	23.90- 20.03	29.64- 29.40	29.64- 29.40
1.1.1.1	Weight	6.20- 3.80	9.64- 9.40	9.64- 9.40
1.1.1.2	Volume	7.70- 6.23	10	10
1.1.1.3	Power	10	10	10
1.1.2	Impact on RPV Design	7.97- 6.68	9.88- 9.50	9.88- 9.80
1.2	Operational Parameters	51.20	48.38	48.38
1.2.1	Guidance and Control Accuracy	10.00	3.18	3.18
1.2.2	Vehicle Dynamic Response	10.00	9.20	9.20
1.2.3	Probability of Successful Recovery	9.70	9.50	9.50
1.2.4	All Weather Potential	10.00	9.00	9.00
1.2.5	Reliability and Maintainability	11.50	17.50	17.50
1.2.5.1	MTBF	2.5	9.0	9.0
1.2.5.2	MTTR	9.0	8.5	8.5
1.3	Tactical Parameters	19.04- 19.17	27.46- 27.46	27.46- 27.46
1.3.1	RPV Approach to Recovery Site Restrictions	10.0	9.0	9.0
1.3.2	Airborne Recovery Signature	5.37	9.06	9.06
1.3.3	Mission Interface Restrictions	3.67- 3.80	9.40- 9.40	9.40- 9.40

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TABLE A-3. (Continued)

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
2.0	Adaptability Field Employment	128.14	94.69	85.67
2.1	Physical Parameters	37.44	17.20	21.54
2.1.1	Setup Size of Components	20.00	2.80	7.20
2.1.1.1	Height	10.00	-0-	4.40
2.1.1.2	Width	10.00	2.80	2.80
2.1.2	Recovery Site Area (Minimum)	7.44	4.40	4.34
2.1.3	Edge Obstruction Height (Maximum)	10.00	10.00	10.00
2.2	Operational Parameters	48.50	41.00	34.50
2.2.1	Crew Size	9.0	8.0	8.0
2.2.2	Crew Skills	10.0	8.0	8.0
2.2.3	Component Transportability	9.5	7.5	7.5
2.2.4	Site Pre-Preparation Time	10.0	7.5	5.0
2.2.5	Geological/Geographical Constraints	10.0	10.0	7.0
2.3	Tactical Parameters	42.50	36.49	29.60
2.3.1	Time to Set Up	9.0	8.0	4.0
2.3.2	Time to Dismantle	10.0	8.0	4.0
2.3.3	Detectability	5.37	9.06	9.06
2.3.4	Concealment	9.83	3.43	4.57
2.3.5	World Wide Operations	8.0	8.0	8.0

TABLE A-3. (Continued)

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
3.0	Serviceableness of Recovery Operations	136.45	122.61	118.71
3.1	Physical Parameters	40.0	31.88	31.88
3.1.1	Approach Window Size	20.0	16.98	16.98
3.1.1.1	Height	10.0	8.49	8.49
3.1.1.2	Width	10.0	8.49	8.49
3.1.2	Approach Angle Limit	10.0	6.90	6.90
3.1.3	Time to Reorient for Wind Shift	10.0	8.0	8.0
3.2	Operational Parameters	62.33	55.92	55.69
3.2.1	Automatic/Manual Recovery Operations	10.0	8.5	8.5
3.2.2	Probability of Recovery w/0 damage	9.0	9.44	9.62
3.2.3	Time to Retrieve RPV and Reset Recovery System	3.33	10.0	6.67
3.2.4	Guidance & Control accuracy Reqmt's	10.0	5.0	5.0
3.2.5	Reliability and Maintainability	30.0	27.99	20.96
3.2.5.1	MTBF	10.0	5.0	10.0
3.2.5.2	MTTR	10.0	8.0	6.0
3.2.5.2	Availability	10.0	9.98	9.98
3.3	Tactical Parameters	34.12	33.81	31.06
3.3.1	All Weather Potential	10.0	9.0	9.0
3.3.2	Access for Retrieval	9.0	8.0	8.0
3.3.3	Mission Interface Restrictions	9.75	7.75	5.00
3.3.4	Unusual Recovery Signatures	5.37	9.06	9.06

TABLE A-3. (Continued)

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
4.0	Suitability for Subdivisional Army Integration	119.08	93.07	84.02
4.1	Physical Parameters	37.50	25.89	26.78
4.1.1	Reduced Dimensions for Transportation	9.0	2.64	4.20
4.1.2	Packaged Weight	9.0	7.75	8.08
4.1.3	M-135 Cargo Truck Compatibility	19.5	15.50	14.50
4.1.3.1	Truck Modification Cost	10.0	8.0	8.0
4.1.3.2	Number of Trucks	9.5	7.5	6.5
4.2	Operational Parameters	43.00	43.00	38.00
4.2.1	Crew Size	9.0	8.0	8.0
4.2.2	Self Mobility	10.0	10.0	10.0
4.2.3	Run for Cover Capability	10.0	8.0	4.0
4.2.4	Logistic Compatibility	5.0	10.0	9.0
4.2.5	Complexity of Operations	9.0	7.0	7.0
4.3	Tactical Parameters	38.58	24.18	19.24
4.3.1	Safety	9.0	8.0	8.0
4.3.2	Concealment	9.83	3.43	4.57
4.3.3	Time to Run for Cover	10.0	5.0	1.67
4.3.4	Mission Interface Restrictions	9.75	7.75	5.0

TABLE A-3. (Continued)

Item No.	Evaluation Parameter	Group I	Group II	
		Parachute	Traveling Net	Traveling Net + I. P.
5.0	Cost and Risk	94.47/91.90	86.97/86.87	79.19/79.09
5.1	Development Cost	13.01/12.05	15.21/15.11	14.56/14.46
5.1.1	Air Vehicle Equipment	3.01/ 2.05	9.86/ 9.76	9.86/ 9.76
5.1.2	Ground Equipment	10.0	5.35	4.70
5.2	Procurement Cost	18.95/18.40	18.08	17.46
5.2.1	Air Vehicle (Unit/1,000 Production)	8.95/ 8.40	10.00	10.00
5.2.2	Ground Equipment (Unit/50 Production)	10.00	8.08	7.46
5.3	Life Cycle Cost (10 year per division)	34.11/33.05	29.19	27.87
5.3.1	Development Costs	9.65/ 9.60	5.34	4.69
5.3.2	Procurement Costs	17.60/16.94	15.95	14.75
5.3.2.1	Recovery System	9.47/ 9.20	6.16	4.91
5.3.2.2	Initial Spares	8.13/ 7.74	9.79	9.84
5.3.3	Support Costs	6.86/ 6.51	7.90	8.43
5.4	Risk	28 28.40	23.83	22.10
5.4.1	Probability of Successful Demonstration	10.00	9.00	9.00
5.4.2	Probability of Meeting Costs	10.00	9.00	8.00
5.4.3	Probability of Survival 2-5 km from FEBA	8.40	5.83	5.10

TABLE A-4. ADJUSTED SCORE

Item No.	Evaluation Parameter	Weight	Group I	Group II	
			Parachute	Traveling Net	Traveling Net + I. P.
	TOTAL SYSTEM	1,000	868.43/855.01	775.64/774.86	732.92/732.14
1.0	Accommodation by Mini RPV	200	152.32/144.01	180.66/180.13	180.66/180.1
1.1	Physical Parameters	66.67	53.12/44.52	65.87/65.34	65.87/65.34
1.2	Operating Parameters	66.67	56.89	53.76	53.76
1.3	Tactical Parameters	66.67	42.31/42.60	61.03	61.03
2.0	Adaptability to Field Employment	200	183.74	132.00	115.21
2.1	Physical Parameters	66.67	62.40	28.67	23.21
2.2	Operational Parameters	66.67	64.67	54.67	46.00
2.3	Tactical Parameters	66.67	56.67	48.66	46.00
3.0	Servicability of Recovery Operations	200	182.90	162.75	157.95
3.1	Physical Parameters	66.67	66.67	53.14	53.14
3.2	Operational Parameters	66.67	59.36	53.26	53.04
3.3	Tactical Parameters	66.67	56.87	56.35	51.77
4.0	Suitability for Subdivisional Army Integration	200	179.59	140.79	127.38
4.1	Physical Parameters	66.67	62.50	43.15	44.64
4.2	Operational Parameters	66.67	57.34	57.34	50.67
4.3	Tactical Parameters	66.67	59.75	40.30	32.07
5.0	Cost and Risk	200	169.88/164.77	159.44/159.19	151.72/151.47
5.1	Development Cost	50	32.53/ 30.13	38.03/37.78	36.40/36.15
5.2	Procurement Cost	50	47.38/ 46.00	45.20	43.65
5.3	Life Cycle Cost (10 yr. per Div)	50	42.64/ 41.31	36.49	34.84
5.4	Risk	50	47.33	39.72	36.83